Ontario Geological Survey
Study 20

Nickel Sulphide Deposits

Associated with Ultramafic Rocks of the Abitibi Belt and Economic Potential of Mafic-Ultramafic Intrusions

by

Paul R. Coad

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MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS

All the measurements in this report are given in the units used in the source materials or in the original measuring. If the reader wishes to convert Imperial Units to Metric or SI Units or SI Units to Imperial Units the following multipliers should be used:

Unit	*Multiplied by*	*Gives*	*Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039	inches	1 inch	25.4	mm
1 cm	0.394	inches	1 inch	2.54	cm
1 m	3.281	feet	1 foot	0.3048	m
1 km	0.621	miles (statute)	1 mile (statute)	1.609	km
			AREA		
1 cm^2	0.155	square inches	1 square inch	6.452	cm^2
1 m^2	10.764	square feet	1 square foot	0.093	m^2
1 km^2	0.386	square miles	1 square mile	2.590	km^2
1 m^2	0.000247	acres	1 acre	4046.686	m^2
1 h	2.471	acres	1 acre	0.405	h
			VOLUME		
1 cm^3	0.061	cubic inches	1 cubic inch	16.387	cm^3
1 m^3	35.315	cubic feet	1 cubic foot	0.028	m^3
			CAPACITY		
1 l	1.760	pints	1 pint	0.568	l
1 l	0.880	quarts	1 quart	1.137	l
1 l	0.220	gallons	1 gallon	4.546	l
			MASS		
1 g	0.035	ounces (avdp)	1 ounce (avdp)	28.350	g
1 g	0.032	ounces (troy)	1 ounce (troy)	31.103	g
1 kg	2.205	pounds (avdp)	1 pound (avdp)	0.454	kg
1 kg	0.0011	tons (short)	1 ton (short)	907.185	kg
1 t	1.102	tons (short)	1 ton (short)	0.907	t
1 kg	0.000984	tons (long)	1 ton (long)	1016.047	kg
1 t	0.984	tons (long)	1 ton (long)	1.016	t
			CONCENTRATION		
1 gm/t	0.029	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.292	gm/t
1 gm/t	0.583	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.715	gm/t
1 ounce (troy)/ ton (short)	20.0	pennyweights/ ton (short)	1 pennyweight/ ton (short)	0.05	ounce (troy)/ ton (short)

Suggestion: Although the above conversion factors are given to several decimal places for your convenience, do not attempt to convert an approximate measurement to a precise measurement. For example, "about 1000 feet" should be converted to "about 300 m" rather than "304.8 m".

ABSTRACT

Many nickel sulphide deposits in the Abitibi Greenstone Belt appear to be of the volcanogenic type, are located in extrusive ultramafic flows, and form an intricate part of Archean eugeosynclinal volcanism. Deposits of this association include the Langmuir, Texmont, and Hart Deposits. The Alexo, Sothman, and McWatters Deposits represent deposits which occur in thin lenticular lenses of dunite with pyroxene-rich peridotitic margins. The exact mode of emplacement of this type of deposit has not been previously documented, however, certain features at the Alexo Deposit suggest an extrusive origin. All of the above deposits belong to the komatiitic magma suite; and all but the Alexo Deposit appear to occur at one stratigraphic level near the base of the Tisdale Group. Features observed at these deposits and other similar nickel sulphide deposits in the various shield areas of the world suggest that a magmatic-volcanic-exhalative type of origin best explains this type of deposit.

Various nickel deposits in Australia, Canada, and South Africa indicate that intrusive and extrusive komatiite may host nickel sulphide mineralization, but the latter is a more common host. Although layered ultramafic intrusions are generally barren of significant nickel-mineralization, they generally underlie extrusive ultramafic rocks, and in this respect may be useful for the exploration of volcanogenic nickel sulphide deposits.

A number of features may be considered when exploring for volcanogenic nickel sulphide deposits. Stratigraphic position and type of ultramafic and geological environment appear to play the most important roles in localizing deposits of this type.

It is important to realize that mafic intrusions and layered intrusions representative of the tholeiitic magma suite may host rich concentrations of copper and nickel mineralization.

Nickel Sulphide Deposits

Associated with Ultramafic Rocks of the Abitibi Belt and Economic Potential of Mafic-Ultramafic Intrusions

by

Paul R. Coad[1]

INTRODUCTION

Since the discovery in the late 1960s of numerous nickel sulphide deposits in the Eastern Goldfields area of Western Australia (Woodall and Travis 1969; Ewers and Hudson 1972), significant advances have been made about the understanding of volcanogenic nickel sulphide deposits.

The study of the Australian discoveries, coupled with work in South Africa (Viljoen and Viljoen 1969) and Canada (Naldrett and Mason 1968; Pyke *et al.* 1973), demonstrate that volcanic rocks with ultramafic compositions do exist, and also show that these ultramafic rocks form an integral part of the volcanic stratigraphy of Archean greenstone belts representing early eugeosynclinal volcanism. These synvolcanic ultramafic units, which often host nickel sulphide deposits, exhibit strong stratigraphic control in the Eastern Goldfields area of Western Australia where most deposits occur in ultramafic volcanic rocks associated with the lower of two volcanic cycles. Each cycle is represented by a lower unit of interbedded ultramafic and basaltic flows, an intermediate unit of acid pyroclastic rocks and related sedimentary rocks, and an upper sedimentary unit of greywacke, shale, and grit, possibly of volcanic derivation (Gemuts and Theron 1975). The lower of these two cycles rests on a thick, banded iron formation, underlain by felsic and mafic volcanic rocks and greywacke. Similar stratigraphic control appears to exist in the Abitibi Greenstone Belt of Canada where a number of volcanogenic nickel deposits occur.

Ultramafic rocks of the synvolcanic association include extrusive and intrusive varieties which can be subdivided into two distinct magmatic suites: 1) the highly-magnesian komatiitic suite, characterized by spinifex-textured ultramafic flows, a low FeO/(FeO + MgO) ratio, where total iron is expressed as FeO for a

[1]Geologist, Ontario Geological Survey. Present address: Texasgulf Canada Limited, Timmins, Ontario. Manuscript accepted by the Chief of The Mineral Deposits Section, Ontario Geological Survey, 12 March 1977. This report is published with the permission of E.G. Pye, Director, Ontario Geological Survey.

given Al_2O_3 content, and relatively low TiO_2 contents; and, 2) a less magnesian tholeiitic suite, lacking spinifex texture and having a higher FeO/(FeO + MgO) ratio and TiO_2 content (Naldrett and Cabri 1976).

Both magmatic suites host major nickel sulphide deposits; but it is the komatiitic suite which is considered to be the most favourable host for such ore (Naldrett and Cabri 1976) as more deposits are known to co-exist with a komatiitic-type host rock.

The term komatiite was first introduced by M.J. Viljoen and R.P. Viljoen (1969) to describe a distinct series of magnesian-rich rocks in the Komati River area in the Transvaal of South Africa. After somewhat restrictive usage of the word by C. Brooks and S.R. Hart (1974), and complications arising from the original definition, the komatiitic suite was subsequently redefined by N.T. Arndt *et al.* (1976) to include a much wider range of members. In this definition, it is proposed that members of the komatiitic suite range from dunite (40 percent MgO) through peridotite (30 to 40 percent MgO), pyroxene peridotite (20 to 30 percent MgO), pyroxenite (12 to 20 percent MgO), magnesian basalt (10 to 12 percent MgO) to basalt (10 percent MgO). All values are calculated on an anhydrous basis. The magnesian-rich peridotite and dunite members of the suite host most economic nickel sulphide deposits. A.J. Naldrett and L.J. Cabri (1976) further define komatiite by indicating that spinifex textures and the presence of olivine-rich extrusive rocks within an igneous suite are pertinent field characteristics. Ideally all of these characteristics should be present to properly describe an ultramafic body as being komatiitic.

In the Abitibi Greenstone Belt, extrusive peridotitic komatiites are extremely well exposed in Munro Township, 30 km west of Matheson, Ontario. Here, D.R. Pyke *et al.* (1973) have described typical peridotite flows made up of a lower zone containing closely packed, equant olivine grains, overlain by a zone in which olivine develops as elongate, thin parallel to randomly oriented crystals (spinifex) which is capped by a fine-grained, quenched, and polygonally fractured crust. These flows are interpreted by Pyke *et al.* (1973) as being the result of the submarine extrusion of ultramafic magma carrying roughly 20 to 30 percent of olivine phenocrysts in suspension. The dense olivine phenocrysts settle to the bottom of the flow, while the overlying liquid becomes supercooled and develops the characteristic spinifex texture. Many flows appear to have been extruded at somewhat lower temperatures, the olivine phenocrysts have been unable to settle in the cooler and therefore more viscous magma, and the flows have solidified as bodies with more or less, uniformly distributed olivine and no characteristic spinifex zone (Naldrett and Arndt 1976).

The majority of nickel sulphide deposits in the Abitibi Belt appear to belong to the synvolcanic-orogenic type of deposit described by A.J. Naldrett (1973). These deposits, together with other Canadian nickel deposits, have been described by various people:

A descriptive classification of various Canadian nickel sulphide deposits into an orogenic and volcanic type was presented by L.C. Kilburn *et al.* in 1969:

The geochemistry of some Canadian nickeliferous intrusions from the Cape Smith-Wakeham Bay Belt of the Ungava Peninsula, Manitoba Nickel Belt, and the Timmins area was described by H.D.B. Wilson *et al.* 1969;

In their classification of Archean nickel sulphide deposits in Canada, Naldrett and Gasparrini (1971) presented a tabular description of the Sothman, Texmont, Alexo, and Langmuir Deposits located in the Ontario part of the Abitibi Belt;

A brief description of the nickel sulphide deposits near Timmins is included in a paper devoted to the distribution and characteristics of the sulphide ores of the Timmins area (Pyke and Middleton 1970); and

O.R. Eckstrand (1972; 1973) has more recently emphasized the volcanic or subvolcanic origin of the various nickel sulphide deposits in the Abitibi Greenstone Belt.

A nickel project was commenced by the Mineral Deposits Section, Ontario Geological Survey, during the summer of 1974 under the direction of Dr. M. Jost. Upon Jost's resignation in 1976 the writer, who was Jost's assistant in 1975, completed the field work and this written report.

The purpose of this study is to describe the nickel sulphide deposits in the Abitibi Greenstone Belt of Ontario in light of the new ideas concerning stratigraphic control, geochemistry, and geological environment. The various ideas concerning genesis of the volcanogenic nickel sulphides (Lusk 1976; Ross and Hopkins 1975; Naldrett 1966; 1973) are discussed. Certain features of the Abitibi nickel sulphide deposits indicate that a revision to the most popular genetic model (Naldrett 1973) is warranted. The irregular distribution of nickel sulphide mineralization in various volcanogenic and intrusive ultramafic bodies is documented. The mechanics of ultramafic emplacement are also discussed. Where applicable, the Abitibi deposits will be compared to other volcanogenic nickel sulphide deposits located elsewhere in Archean greenstone belts throughout the world. The economic potential of mafic and ultramafic intrusions is discussed. In conclusion, significant features are listed to assist in the exploration for volcanogenic nickel sulphide deposits.

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Geological Survey, for kindly reviewing the manuscript. Thanks are also extended to all those in the Ministry of Natural Resources who assisted in the completion of this report.

THE ABITIBI BELT

Regional Geology

The Abitibi Belt is located in the Superior Province of the Canadian Shield. The belt is described by A.M. Goodwin (1968; 1973) as being a crudely S-shaped structure, approximately 650 km[1] long and 150 km wide, which extends in an East-Northeast direction from Wawa in central Ontario to Chibougamau in Quebec. The belt is bounded to the north and south by metasediments and gneissic rocks. It is composed principally of volcanic and sedimentary rocks which have undergone regional metamorphism to the lower and middle greenschist facies, except in the aureoles of granitic plutons where grades of upper amphibolite facies are encountered (Jolly 1974). The central part of the belt is shown in Figure 1 (after Goodwin and Ridler 1970).

THE TIMMINS AREA

Local Geology

In the Timmins Area, the early Precambrian metavolcanics comprise two groups, the Deloro Group and the Tisdale Group shown in Figure 2 (after Pyke 1975c). This terminology follows that adopted by W.R. Dunbar (1948), and subsequently used by other workers such as N. Hogg (1950), H.D. Carlson (1967), and E.J. Leahy (1971). The two groups are separated from one another by the Destor-Porcupine Fault. D.R. Pyke (1975c) suggests that ultramafic flows on opposite sides of the fault are correlative, and that the Deloro Group is older than the Tisdale Group. Table 1 (after Pyke 1975c) is a brief outline of the apparent stratigraphic succession from oldest to youngest in the Timmins area.

South of Timmins and the Destor-Porcupine Fault, the main structural feature is a northwest-trending dome, approximately 19 by 29 km, centred in Shaw Township (Figure 2). The eastern periphery of a second dome is partly exposed in the southwest corner of the area in McArthur and Bartlett Townships (Figure 3); granitic batholiths have destroyed all evidence of the western part. A discontinuous peripheral belt of ultramafic rocks outlines both domes, and it is at this particular stratigraphic interval, at the top of the Deloro Group and the base of the Tisdale Group where nickel sulphide deposits are located (Figure 3). These include the Langmuir, McWatters, Hart, and Texmont Deposits. The Sothman Deposit located to the south in Sothman Township is similarly located about a crude domal structure (Pyke, Ayres, and Innes 1973) and appears to be situated

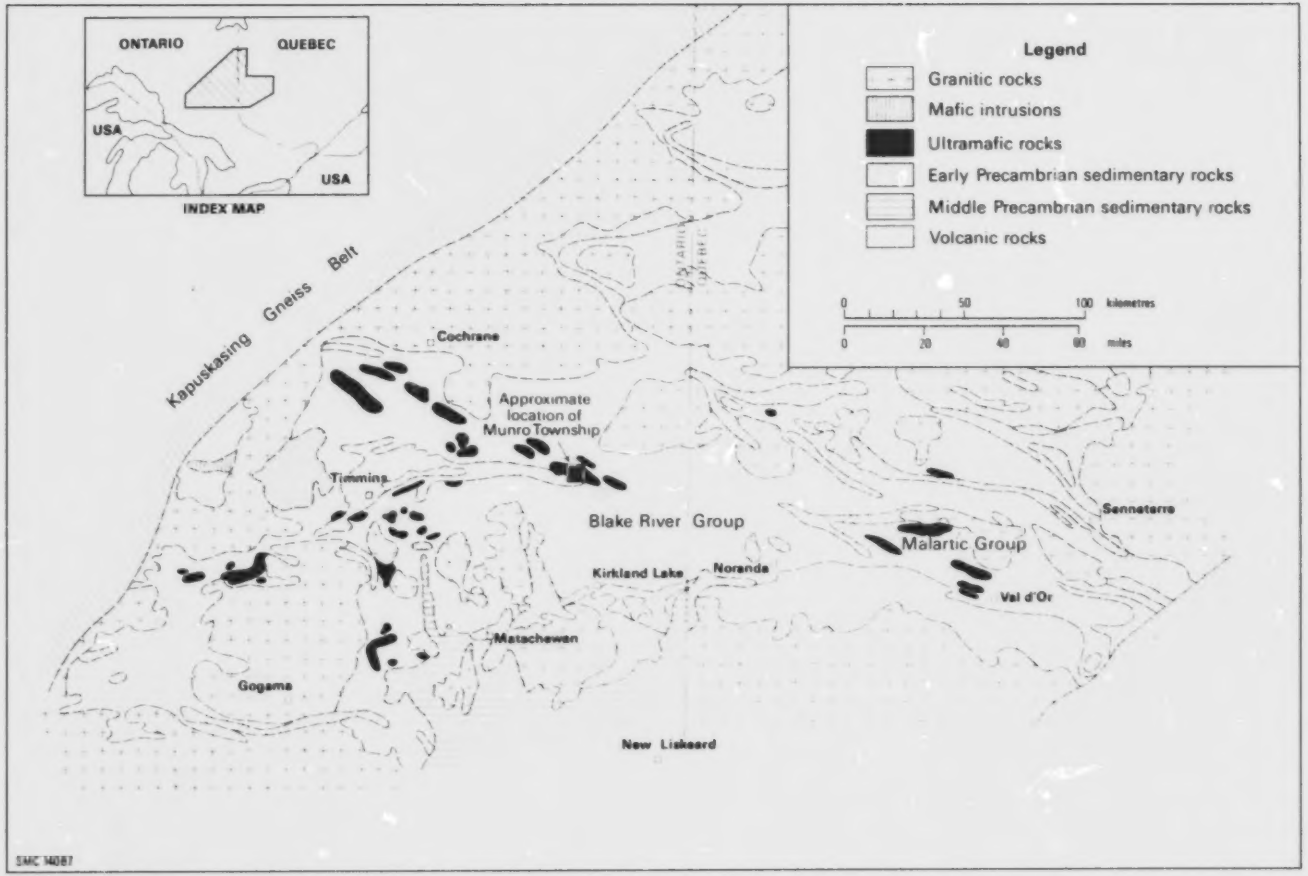

Figure 1–Map of Part of the Abitibi Greenstone Belt, after Goodwin and Ridler (1970) and location of Munro Township.

TABLE 1 DESCRIPTIVE TABLE OF FORMATIONS FOR THE TIMMINS AREA (AFTER PYKE 1975c)

DELORO GROUP

DONUT LAKE FORMATION

Ultramafic metavolcanics - a poor exposure of talcose ultramafic rock near Quartz Lake in the southeast part of the study area probably represents the continuation of the ultramafic metavolcanics outlined in Fripp Township (Pyke 1973), which form part of the lower volcanic cycle in the Peterlong Lake area.

REDSTONE FORMATION

Mafic metavolcanics, consists mainly of calc-alkaline andesite and basalt, with lesser tholeiitic basalt; best exposed in northern Shaw Township and the north and east parts of Deloro Township. Pillow breccia and intercalated tuff and lapilli-tuff are common.

BOOMERANG FORMATION

Intermediate to felsic metavolcanics, composed largely of tuff and lesser tuff-breccia. Interlayered sulphide- and oxide-bearing iron formation is common, and locally serves to outline the sequence in lieu of intermediate to felsic metavolcanics.

TISDALE GROUP

GOOSE LAKE FORMATION

Ultramafic metavolcanics, and high magnesium (greater than 10 percent MgO) basalt.

SCHUMACHER FORMATION

High iron (greater than 12 percent FeO total) tholeiitic basalts appear to dominate: commonly pillowed, locally variolitic, and best developed in Tisdale Township. Interlayered ultramafic metavolcanics are locally common, as in southern Langmuir Township.

KRIST FORMATION

Felsic metavolcanics, largely composed of breccia and tuff-breccia.

UPPER METASEDIMENTARY GROUP (PORCUPINE GROUP)

Metasediments consisting dominantly of interlayered greywacke, siltstone and lesser conglomerate form part of a turbidite sequence, the lower part of which is time equivalent to the Tisdale Group and the upper part of the Deloro Group (Figure 3). This turbidite sequence, together with a thin sequence of overlying fluviatile sedimentary rocks, has recently been classified as the Porcupine Group (Lorsong 1975).

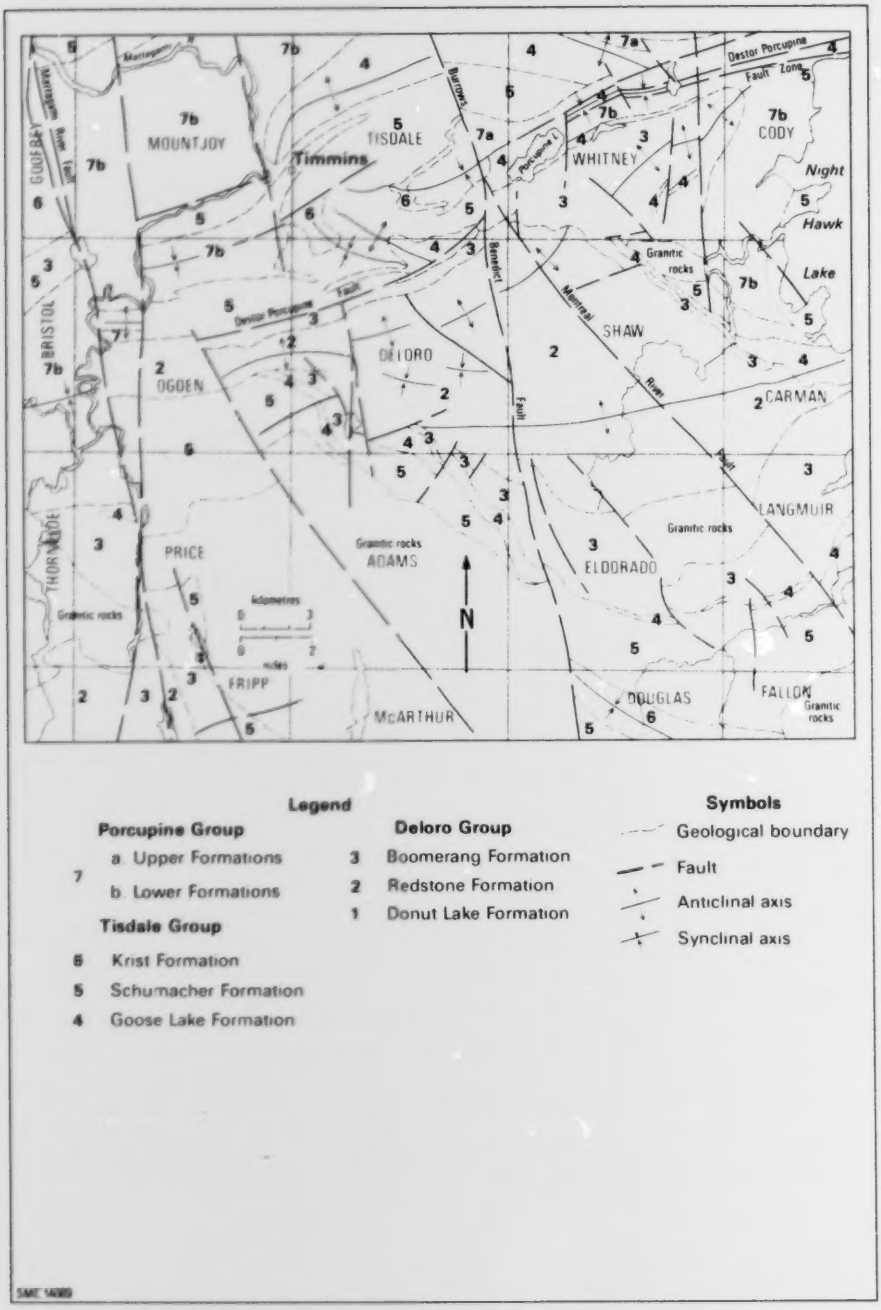

Figure 2–Tentative distribution of stratigraphic units in the Timmins area (after Pyke 1975c).

at the same stratigraphic horizon. The Alexo Deposit is structurally separated from the other deposits by the Destor-Porcupine Fault (Figure 3).

Descriptions of Deposits

LANGMUIR DEPOSIT

Location

The Langmuir Deposit (Number 2 Zone) is located about 32 km southeast of Timmins in Langmuir Township (Figure 3). Another orebody, the Number 1 Zone is located about 1500 m along strike, to the southeast of the Number 2 Zone.

History and Previous Work

The property first received attention in 1959-1960 when Texasgulf Sulphur Company completed an electromagnetic survey and drilled two diamond-drill holes totalling 194.1 m. Results of this work were inconclusive. Between 1964 and 1966, Mining Corporation of Canada Limited (owned by Noranda Mines Limited) conducted an exploration programme consisting of ground magnetometer and electromagnetic surveys, diamond drilling and eventual staking. In 1966, Noranda Mines Limited and INCO reached an agreement by which the property would be developed on a 51 percent Noranda Mines Limited and 49 percent INCO basis. Between 1966 and 1972, geological, ground magnetometer, and electromagnetic surveys were completed and 32 surface diamond-drill holes totalling 7091.5 m were drilled. In 1972, a shaft was sunk to a depth of 444.4 m on the Number 2 Zone with eight levels established. The mill began production in June 1973 at a rated capacity of 700 tons per day. Production figures to December 31, 1975 are:

1973 67,000 tons; grading 1.54 percent nickel;
1974 221,450 tons; grading 1.50 percent nickel; and
1975 261,520 tons; grading 1.46 percent nickel.

Ore reserves as of January 1, 1976 (Number 2 Zone) were 857,528 tons grading 1.75 percent nickel and approximately 0.6 percent copper. Precious metals are also recovered from the ore (unpublished Company Report; Pamour Group).

At present the Number 1 zone is being diamond drilled to properly delineate the ore body. Previous accounts of this deposit include a brief description by L.J. Naldrett and E.L. Gasparrini (1971) and a more recent description by T.L. Muir (1975). Presently the deposit is being investigated by A.H. Green, a Ph.D. candidate at the University of Toronto.

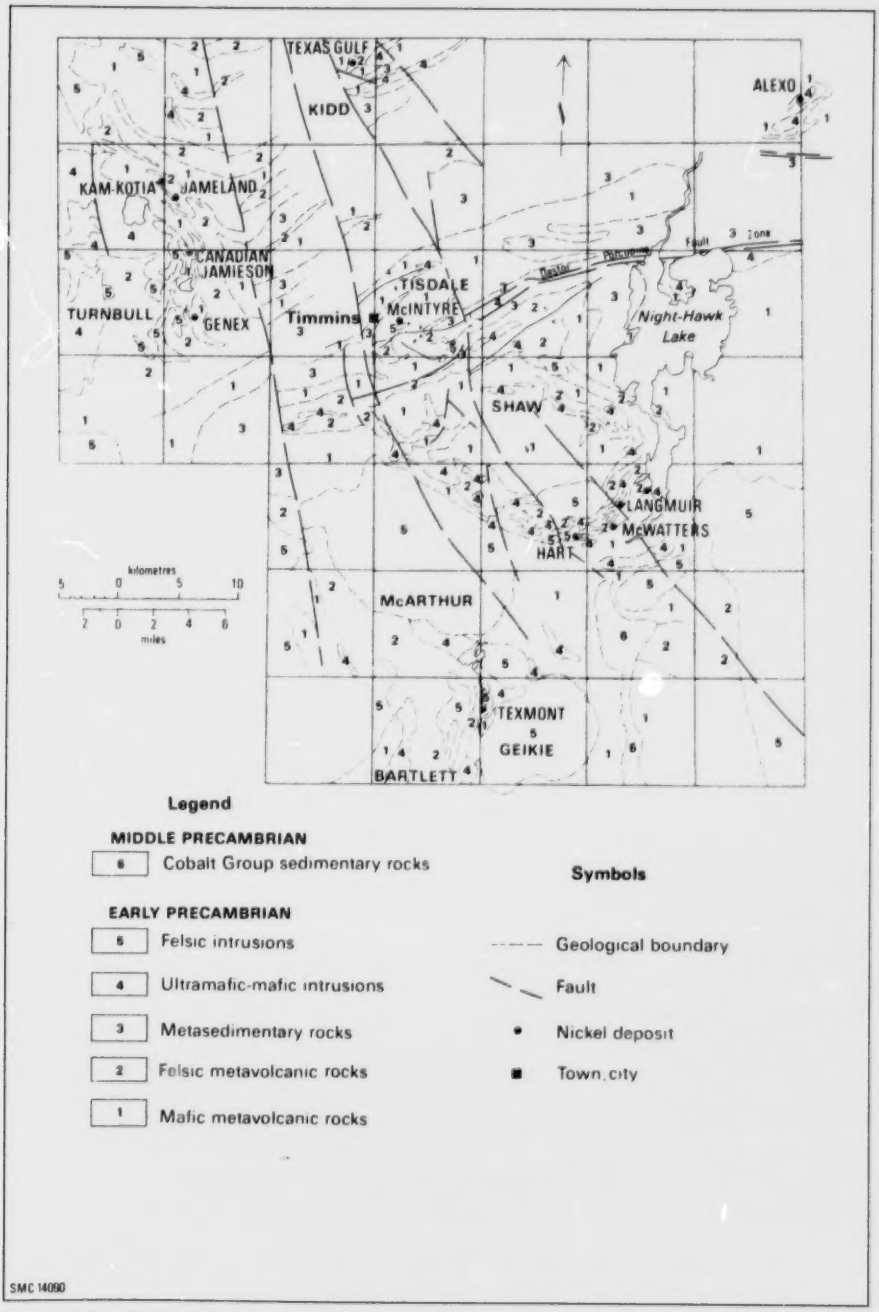

Figure 3–The Timmins Area, general geology and location of nickel deposits (after Pyke and Middleton 1970).

General Geology

The Langmuir ore deposits (Number 1 and Number 2 Zones) are located in a sequence of predominantly extrusive ultramafic volcanic rocks (Tisdale Group) up to about 30 m thick on top of a volcano-sedimentary pile of predominantly felsic-intermediate volcanic rocks including abundant crystal tuff and localized thin cherty sulphide iron formation (Deloro Group). The deposits are located at the southeast margin of the Shaw Dome (Figure 3), the major geological structure in the area. The margins of the Shaw Dome, specifically the stratigraphy in Langmuir and Eldorado Townships, have been subjected to widespread isoclinal folding on a local and regional scale (Pyke 1970, Map 2206).

Extrusive ultramafic volcanic rocks (komatiites), which host the ore, are locally intercalated with intermediate to felsic volcanic rocks of the Deloro Group indicating contemporaneous activity of the two different volcanic series. The ultramafic extrusive rocks are overlain by basaltic flows consisting of a mixture of komatiites and tholeiites, followed by a sequence of ultramafic flows (komatiites) similar to those in Munro Township (Pyke *et al.* 1973).

Extensive faulting and folding combined with poor outcrop exposure makes the tracing of the favourable ore horizon westward difficult. Eastward, the ore horizon curves to the north following the periphery of the Shaw Dome where it may be partly covered by Nighthawk Lake.

Footwall Rocks

In the Number 2 Deposit, footwall rocks, representative of the Deloro Group (Pyke 1975c), consist of massive intermediate to felsic lavas, pyroclastic rocks and less commonly bedded tuffs, chert, and cherty iron formation. The most common variety is massive grey andesitic lava, with local concentrations of calcite-filled amygdules. In places, the lava is brecciated, presumably representing flow tops or lava fronts.

At the contact with peridotite, the underlying footwall lavas are locally bleached a pale grey-green. This may be due to the emplacement effects of the ultramafic flows and the associated nickel sulphide mineralization; but, in areas devoid of nickel sulphides the volcanic rocks are also generally bleached.

In the northern part of the mine, the footwall contact is usually marked by the presence of a coarse intermediate to felsic agglomerate or breccia. Individual fragments measure as much as 30 cm in diameter and are generally angular.

Crosscutting ultramafic dikes up to 2.0 m wide locally intrude the footwall breccias and ore zone in the basal ultramafic flow. These dikes exhibit variable attitudes, and also occur as semi-concordant bodies paralleling the peridotite-volcanic contact, following zones of intense shearing and well-developed lineations. These dikes may represent feeders to overlying flows.

Towards the southern end of the mine, the footwall is characterized by dark green chloritic andesite.

In the Number 1 Zone, footwall rocks consist predominantly of clastic tuffs. Locally the tuff is well bedded parallel to the volcanic-ultramafic contact.

Although spinifex texture is poorly developed and flowtops are ill defined in the basal parts of the ultramafic pile, it would appear that individual flows measure less than 30 m in thickness. In the Number 2 Zone spinifex texture appears to be best developed at higher stratigrphic levels in the ultramafic pile, where flows are less thick and appear to be more continuous along strike. However, in the Number 1 Zone spinifex-textured flows characterize the footwall volcanic contact.

A. Green (1976, personal communication) suggests that three successive flows form the base of the ultramafic sequence: these flows are mineralized having basal concentrations of nickel sulphide mineralization (Figure 4). This interpretation is questionable for basically three reasons:

1) The extensive faulting and shearing which has occurred along the footwall contact;
2) The fact that Green's Number 2 flow in places rests conformably on the footwall contact; and
3) The lack of well-developed features such as spinifex and flow tops to properly delineate these flows. The presence of sulphide mineralization alone should not be used as a flow indicator.

The basal footwall contact is quite irregular down dip and in vertical section 7600N, the basal ultramafic flow unit is intercalated with footwall volcanic rocks (Figure 4). At the seventh level towards the southern end of the ore horizon, the base of the ultramafic sequence appears to be either intrusive or tightly isoclinally folded with intermediate to felsic volcanic rocks of the footwall (Figure 5). Lack of stratigraphic facing in this area makes structural interpretations questionable.

The northern extension of the footwall contact is marked by a downward protruding ultramafic wedge (Figure 5, northeast of the shaft). This wedge has been diamond drilled across strike to the west, up to a distance of 3000.0 m and as yet footwall volcanic rocks have not been intersected. This ultramafic wedge trending west across the stratigraphy is considered to be the intrusive feeder to the overlying flows (A. Green 1976, University of Toronto, personal communication). The probability of isoclinal folding in the immediate mine area makes this interpretation questionable. The wedge-shaped peridotite may represent the nose of a fold because ultramafic flows outcrop near the emergency tailings pond, located 3000 m west of and stratigraphically below the main ore horizon (Figure 5). Margins of the wedge-shaped ultramafic body interfinger with footwall volcanic rocks (Figure 5), and this may represent local small-scale folding. Aeromagnetic data suggest the presence of a fold in this area where the mine stratigraphy forms an anticlinal structure between two synclines (Pyke 1970, Map 2206). The presence of tight isoclinal folding has been recognized by mine staff in the Number 1 Zone located 1500 m to the southwest along strike from the Number 2 Zone. More diamond drilling is required to delineate the structure in the area.

In the Number 1 Zone, ultramafic flows average 2.1 m thick and become progressively thinner up sequence. Spinifex as in the Number 2 Zone, is better developed at higher stratigraphic levels in the ultramafic sequence.

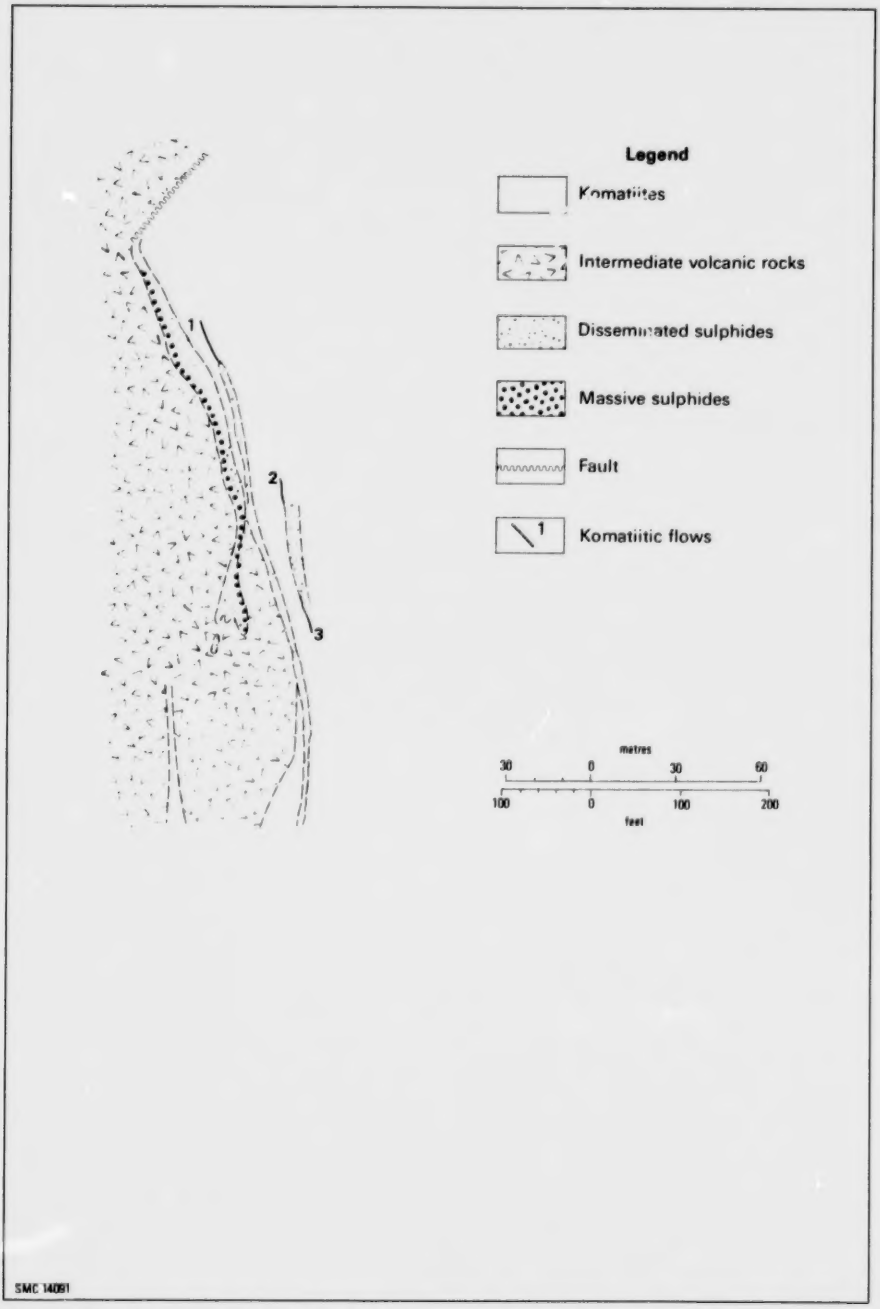

Figure 4–Vertical east-west section of the Langmuir Nickel Mine, looking north at 7600 N (modified after Green 1976).

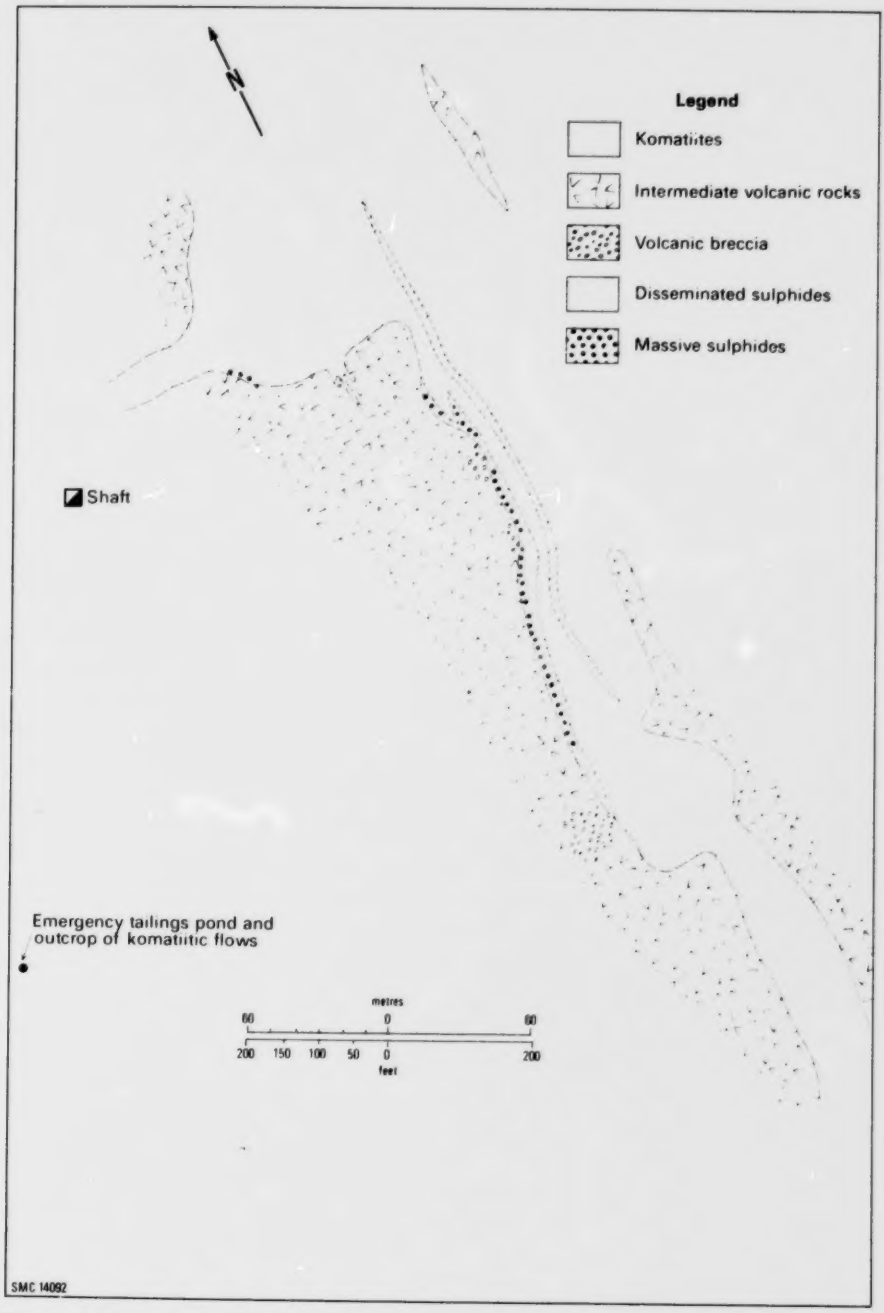

Figure 5–Plan view of the Number 2 Zone on the seventh level, Langmuir Mine (modified after Green 1975).

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Photo 1–Recrystallized grains of pentlandite marking banding in massive ore, Langmuir Deposit. Field of view is 25 cm.

Economic Geology

The ore deposits (Number 1 and Number 2 Zones) occur along the basal contact of the lowermost ultramafic flow unit adjacent to the footwall volcanic rocks (Figure 4). All sulphide mineralization occurs at or within 30 m of the footwall volcanic contact. Four types of nickel sulphide mineralization occur: 1) massive ore; 2) disseminated or net-textured ore (Naldrett 1973); 3) mineralized spinifex textures; and 4) breccia-ore.

Massive ore generally occurs in thin concordant lenses measuring between 0.34 m and 2.51 m thick forming a sharp contact with the basal footwall volcanic rocks. Macroscopically, the massive ore has locally a distinct banded appearance, this banding being parallel to the footwall contact. The banding is marked by the concentration of large pentlandite crystals or "eyes" into distinct 2 mm to 10 mm thick bands. These fine-grained bands are interbedded with thin bands of fine-grained chalcopyrite (Photo 1).

Microscopically, the massive ore has a granular mosaic type of texture consisting of recrystallized grains of pyrrhotite and pentlandite (Photo 2). Pentlandite occurs as large (1.0 mm) crystals in the granular mosaic or as average sized (0.5 mm to 0.8 mm) grains about grains of pyrrhotite. Minor chalcopyrite generally occurs as minute grains interstitial to pyrrhotite grains, however, it is locally recrystallized into a granular mosaic in areas of thin chalcopyrite-rich layers. Magnetite is locally present in the massive ore as anhedral grains occupying in-

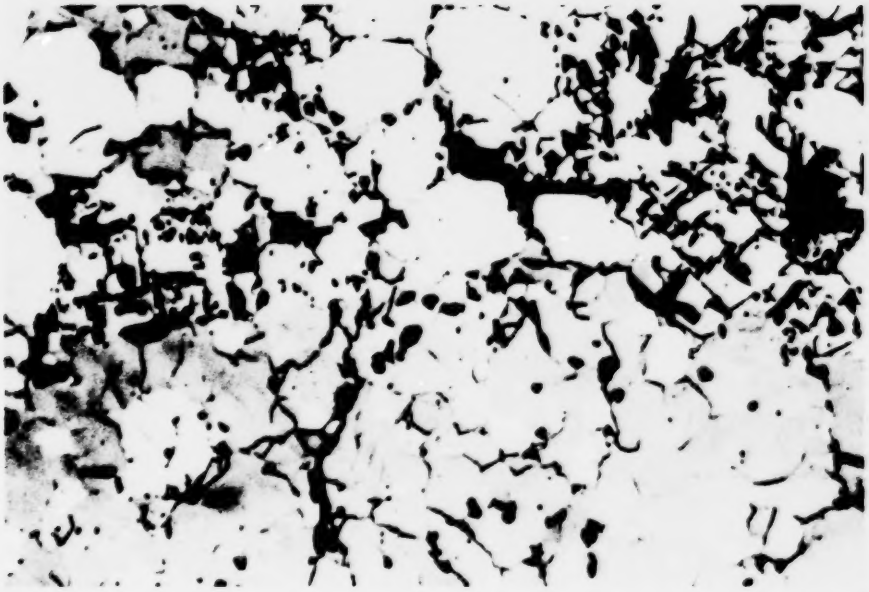

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Photo 2–Photomicrograph showing recrystallized grains of pyrrhotite and pentlandite in massive ore, Langmuir Deposit, specimen J75-16. Field of view is 3.3 mm.

tergranular spaces between pyrrhotite and pentlandite. Modal analyses indicate subhedral crystals of pyrite may form up to 10 percent of the ore occupying similar positions to the magnetite. Anhedral and euhedral chromite, mantled by magnetite occurs localy in bands enhancing the banded nature of the massive ore. Generally, chromite is concentrated at the base or at the top of the massive ore in layers up to 10 cm thick.

The top of the massive ore is generally in sharp contact with overlying disseminated sulphide mineralization or net-textured sulphides. This zone of net-textured sulphides is of variable thickness ranging from 1.0 to 3.0 m thick. The net-textured sulphide minerals occupy intercumulate positions between equant olivine crystals which have been serpentinized and carbonatized (Photo 3). In places, the massive ore is overlain by barren peridotite, and locally the mineralized horizon is simply marked by disseminated sulphides without associated massive ore.

Thin lenses of massive nickel sulphide ore also occur locally within the footwall intermediate to felsic volcanic rocks. These lenses can be traced along strike into zones of massive sulphide mineralization which lie in sharp contact with overlying net-textured sulphide minerals in peridotite. These massive ore lenses located in the footwall volcanic rocks may be the result of: 1) contemporaneous nickel sulphide mineralization and intermediate to felsic volcanic activity, or

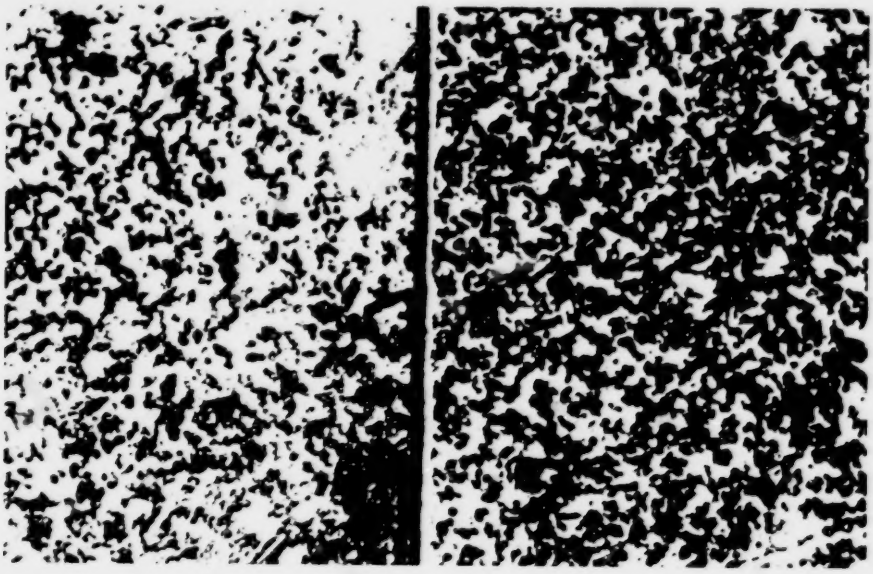

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Photo 3–Split diamond-drill core illustrating net-textured sulphides. Pentlandite and pyrrhotite occupy the matrix areas between serpentinized grains of olivine. Diamond-drill core measures 6.0 cm in length. Specimen from Number 1 Zone, Langmuir Deposit.

2) the result of tight isoclinal folding. The latter explanation seems more likely as thin lenses of massive ore occur in the footwall tuff in the Number 1 Deposit where tight isoclinal folding is recognized. When the structure of these lenses is unravelled, they can be traced along strike into zones of massive sulphide mineralization between footwall volcanic rocks and overlying ultramafic flows.

In places, pods or lenses of massive ore occur within the footwall volcanic rocks in the Number 2 Deposit, some are 15 m below the main ore horizon. The exact nature of these isolated pods is difficult to discern. However, these sulphide pods or lenses can be traced upward into zones of mineralization between footwall volcanic rocks and overlying ultramafic flows.

Sulphide mineralization also occurs in the spinifex parts of the basal ultramafic flow in the Number 2 Deposit where the flow thins in one locality close to the footwall. Locally, this mineralization will constitute ore. Here pyrrhotite, pentlandite, and minor pyrite occupy areas between blades of olivine usually marked by feathery pyroxene and devitrified glass (Pyke *et al.* 1973). Locally, the sulphides are altered to fine-grained magnetite. Areas of mineralized spinifex texture are also present in the Number 1 Deposit, in flows close to the footwall contact. Photos 4 and 5 illustrate the intricate relationship between elongate olivine blades and interblade areas filled by recrystallized sulphides.

OGS 9891

Photo 4–Recrystallized pentlandite and pyrrhotite and minor pyrite between elongate blades of serpentinized olivine. Specimen from Number 2 Zone, Langmuir Deposit. Field of view is 8 cm.

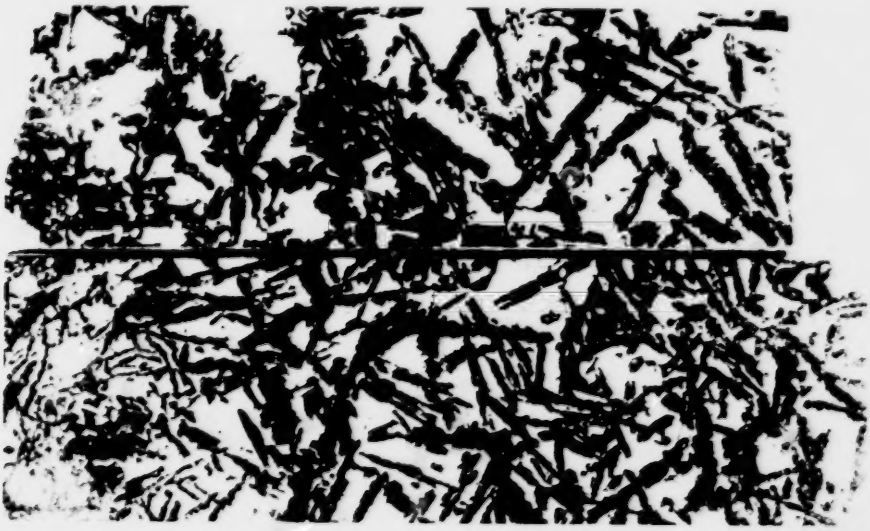

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Photo 5–Mineralized spinifex texture in diamond-drill core from Number 1 Zone, Langmuir Deposit. Specimen measures 6 cm in length.

OGS 9893

Photo 6–Angular and subrounded fragments of peridotite in massive ore, photo taken underground, Langmuir Deposit.

Breccia-ore consists of irregularly-shaped and irregularly-sized fragments of massive peridotite in a matrix of massive recrystallized sulphides (Photo 6). The fragment to sulphide ratio is quite variable. This, together with the ill-defined borders of the peridotite fragments, would suggest that the ore has resulted from some type of tectonic deformation involving remobilization of once massive sulphide ore. This type of ore is restricted to the footwall contact where ultramafic flows are in contact with underlying intermediate to felsic volcanic rocks. In thin section, the fragments consist of feathery pyroxene and devitrified glass with lantern-shaped crystals of olivine forming up to 30 percent by volume of the fragment. This type of silicate mineralogy and proportion of minerals present is rather characteristic of the margins of an ultramafic flow. Sulphide mineralogy of the breccia ore is similar to that of the massive ore and it is invariably recrystallized.

Irregularly shaped lenses of semi-massive to disseminated sulphide mineralization occur above the footwall contact and the main ore horizon. These lenses, as previously stated, are considered to represent the basal parts of two overlying mineralized ultramafic flows (A. Green 1976, University of Toronto, personal communication). The exact nature of these mineralized zones is not clear. They might represent segments of the original footwall mineralization which have been subsequently deformed or remobilized into place. Evidence to indicate this includes:

1) The occurrence of isoclinal folding in the volcanic stratigraphy marginal to the Shaw Dome;
2) The presence of strong shearing near the footwall volcanic rocks and overlying ultramafic rocks;
3) The abundant talc-carbonate alteration which accompanies sulphide mineralization located away from the footwall and main ore horizon;
4) The high proportion of pyrite and magnetite mineralization associated with the overlying zones;
5) The patchy and irregular nature of the overlying zones;
6) The closeness of these zones to the footwall, less than 30 m; and
7) The presence of breccia-ore and evidence of structural deformation of the main ore horizon.

The "south-zone" orebody in the Number 2 Deposit is characterized by disseminated mineralization in a sill-like or folded ultramafic body (see section on "Host Rocks") located to the south along strike from the main ore zone (Figure 5). Sulphide mineralogy consists of pyrite and millerite in a fine-grained cumulate textured peridotite. The peridotite is serpentinized and carbonatized to varying degrees. Spinifex texture has not been recognized in this peridotite body.

Footwall volcanic rocks are generally extensively mineralized by fine-grained disseminated to coarse-grained euhedral pyrite in the vicinity of massive nickel sulphide minerals. Grades of 0.5 to 1.0 percent nickel are locally reported in the footwall volcanic rocks and breccia (A. Green 1976, University of Toronto, personal communication). Also, trace amounts of sphalerite are locally present in the footwall volcanic rocks. In one footwall diamond-drill hole intersection, the massive ore is underlain by a 1.0 m thick horizon of tuff which is mineralized by iron sulphides and minor nickel sulphides. This tuff unit is underlain by pyrite-bearing cherty iron formation which in turn is underlain by footwall intermediate to felsic volcanic breccia. The original composition and texture of the tuff is not known as it has been extensively chloritized and carbonatized. Parallel thin bands of pyrite mineralization, concordant to the footwall contact, occur throughout the tuff. Along strike from this intersection, nickel sulphide mineralization tapers off abruptly. This particular intersection can be traced from the upper to the lower levels of the mine. A cross fault which cuts this intersection appears to have been contemporaneous with volcanism and sulphide mineralization.

TEXMONT DEPOSIT

Location

The location of the Texmont Deposit straddles the boundary between Geikie and Bartlett Townships about 35 km south of Timmins (Figure 3). The shaft is located almost directly on the boundary between the two townships and about 2.8 km south of the north boundary.

History and Previous Work

The property was first staked in 1950 as an asbestos prospect by Dominion Gulf Company. The presence of nickel was discovered in 1951 and the company subsequently conducted an exploration programme consisting of prospecting, geological mapping, geophysical surveys, and diamond drilling. The claims were optioned in 1956 by Fatima Mining Company Limited, and purchased by that company the following year after diamond drilling 23 holes totalling a length of 1888 m. A geochemical survey was carried out in 1956, and an additional 8190 m of surface drilling was completed by November 1959. Also in 1959, a three-compartment shaft was sunk to a depth of 239 m and stations established at 45 m, 90 m, 136 m, 180 m and 224 m. In 1960, 469 m of drifting and crosscutting were completed on the 136 m level, and 439 m of lateral work and 75 m of raising on the 224 m level. A total of 5050 m of diamond drilling in 168 holes was also completed (Leigh 1971).

In 1964, Fatima Mining Company Limited was renamed Texmont Mines Limited. In 1956 an agreement for further development of the property was entered into with the Canadian Nickel Company by which that company acquired a 15 percent interest in the property. During 1965-1966, a total of 28 893 m of diamond drilling in 74 surface holes was completed.

In 1970, a production agreement was reached with Sheridan Geophysics Limited. Under the terms of this agreement the claims were leased to Sheridan Geophysics Limited for a period of 20 years with the right to renew for a further 20-year period.

Mill production began on July 1, 1971, at a rated capacity of 500 tons per day with provision to expand to 1000 tons per day. At this time, a new hydrometallurgical smelter was built on the property to produce about 200,000 lbs of refined nickel products per month. Since production started, the concentrate (grading 17 percent nickel) has been stockpiled and some basic nickel sulphate sold to chemical industries.

In December 1972, mining and milling operations were suspended temporarily due to the high cost of diesel fuel used to produce electricity for the mine. Smelter operations have continued intermittently to the present day using stockpiled concentrate. In 1975, the fuel oil tax was rescinded and shipments of nickel concentrate were sent to Europe (Canadian Mines Handbook 1976). At present, the possibility of reopening the mine is being assessed.

Based on the results of work to date, reserves have been calculated at 3,800,000 tons grading 1 percent nickel after dilution, to a depth of 488 m, 2,500,000 tons in the Main Zone, and 1,300,000 tons in the South Zone (Leigh 1971). Three diamond-drill holes below this depth indicate an additional potential of 1,000,000 tons to a depth of 605 m, with the zone still open and untested below this depth (Leigh 1971).

Initial reports of the Texmont Deposit include brief descriptions by Naldrett (1966), Shklanka (1969) and Pyke and Middleton (1970). Recently, Eckstrand (1972; 1973) has reported the presence of spinifex at the Texmont Deposit and the possibility of a synvolcanic or subvolcanic origin. Further descriptions of the deposit are provided by O.R. Eckstrand and A.R. Miller (1973) and Pyke (1975b).

General Geology

The Texmont Deposit is located in a steeply dipping sequence of ultramafic flows which strikes north-south and measures up to 300 m thick (Figure 6). Footwall rocks consist of felsic tuff, volcanic breccia, siltstone, and sulphide-oxide iron formation representing rocks of the Deloro Group (Pyke 1975c). The ultramafic sequence is marked by thin intercalated beds of siliceous and locally carbonaceous sedimentary rocks which have been subsequently intruded by semi-concordant dikes and sills.

The basal 105 m of the ultramafic sequence is marked by flows measuring 15 m to 30 m thick. Actual flow tops are not identified in diamond-drill core. However, the presence of spinifex texture, and beds of siliceous sedimentary rocks are considered to represent interflow boundaries (Eckstrand 1972). Spinifex is poorly developed in the basal part of the ultramafic sequence, but the upper parts of the sequence consist of spinifex-textured flows not unlike those described in Munro Township (Pyke *et al.* 1973b).

The mine stratigraphy has been subjected to considerable cross faulting with displacements measuring up to 53 m (Figure 6). Rocks are locally carbonatized in the vicinity of fault zones.

Footwall Rocks

Footwall rocks consist of light buff coloured, fine-grained intermediate to felsic volcanogenic sedimentary rocks and tuff. These sedimentary rocks are invariably mineralized by disseminated pyrrhotite, pyrite, and minor chalcopyrite. Thin 10 cm concordant layers of granular magnetite and pyrrhotite occur throughout the tuff imparting a distinct layering to the rock. Locally, thin layers 0.5 cm thick of pyrrhotite are intercalated with granular magnetite.

The peridotite-volcanic rock contact is generally marked by fine-grained tuff, but locally this contact has been intruded by concordant gabbro-sills. These intrusive bodies generally have chilled margins ranging from 2 cm to 15 cm thick. The gabbroic rocks have been extensively altered, but relict subophitic intergrowths of pyroxene and plagioclase were recognizable.

Siliceous volcanic breccia is well developed near line 5000N (Figure 6). Here, white, angular, siliceous fragments measure between 4 cm and 40 cm in diameter (Photo 7). The matrix between the fragments consists of fine-grained tuffaceous material and finely disseminated pyrrhotite and minor pyrite which, as a result of oxidation, impart a distinct brown colour to the weathered surface.

Host Rocks; Extrusive Ultramafic Volcanic Rocks

Basal parts of the ultramafic sequence outcrop as low, flat-surfaced exposures. The peridotite generally weathers to a brownish white and is black-green on fresh surfaces. The serpentinized peridotite is fine grained. Locally cumulate

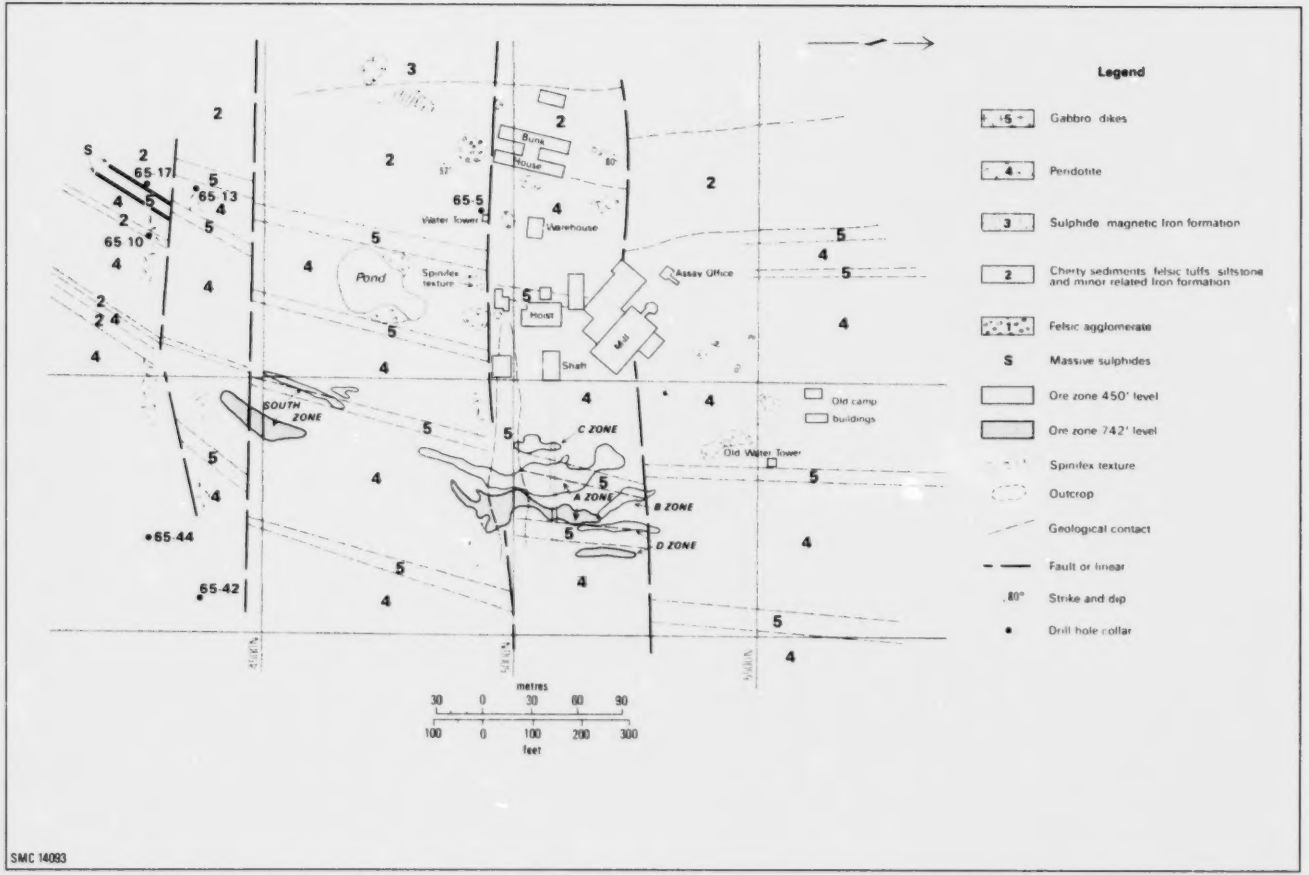

Figure 6–Map illustrating geology about Texmont Mines Limited property (modified after Pyke 1975b).

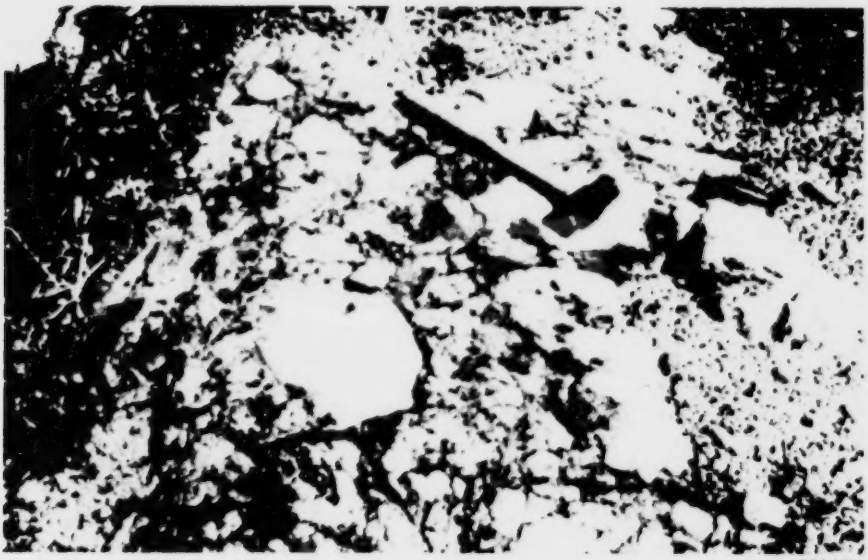

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Photo 7–Angular fragments of intermediate to felsic volcanic in tuffaceous matrix, Texmont Deposit.

textures are well preserved on weathered surfaces where equant olivine grains range from 1.0 mm to 2.0 mm in diameter. Vesicle-like structures, measuring up to 2 cm in diameter, occur in one peridotite outcrop, located north of the headframe. These oval- to elongate-shaped structures may represent carbonate-filled amygdules which have subsequently weathered out (Photo 8). One small outcrop of massive peridotite occurs in the footwall rocks near the bunkhouse (Figure 6).

Spinifex textures, as mapped by Pyke (1975b) are located in an ultramafic rock outcrop near the ventilation building (Figure 6). This outcrop weathers a distinct red-brown reflecting its relatively high magnesium content and komatiitic character. The texture is characterized by elongate 2 to 5 cm blades of olivine which are randomly oriented in subparallel sheaths (Photo 9). The texture is not as coarse or so well developed as textures described in Munro Township (Pyke *et al.* 1973b). Irregularly shaped and sized (10 cm) patches of spinifex texture are randomly distributed in peridotite outcrops located south and east of the main spinifex-bearing outcrop (Figure 6). These local occurrences of spinifex are volumetrically insignificant and poorly defined.

In thin section, the ultramafic rocks are seen to have been completely altered to serpentine, and locally carbonate and/or talc is extensively developed. Relict cumulate textures are now marked by serpentine pseudomorphous after equant olivine grains. Margins of relict olivine grains are normally rimmed by fine-grained magnetite. Olivine generally constitutes more than 85 percent by volume of the cumulate-textured peridotite, but matrix minerals consisting of

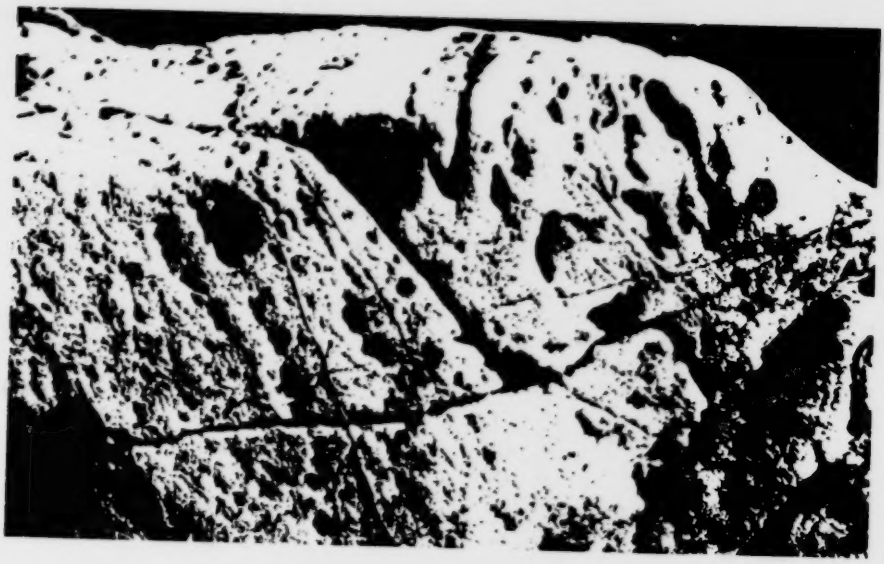

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Photo 8–Irregularly-shaped structures in peridotite resembling vesicles, Specimen C76-162, Texmont Deposit.

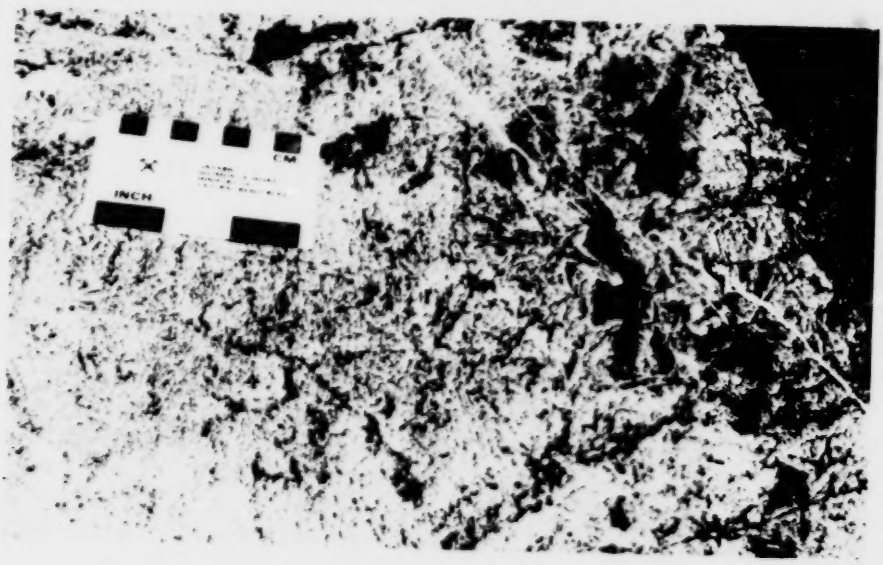

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Photo 9–Surface outcrop of spinifex-textured peridotite, Texmont Deposit.

fine-grained chlorite, serpentine, feathery pyroxene, chromite and magnetite may together form as much as 15 to 20 percent of the rock. Chromite generally forms individual euhedral crystals. Cruciform chromite was observed in some specimens where euhedral chromite grains are stacked one upon the other in a row. The degree of packing of olivine grains is quite variable. In certain specimens, fine-grained carbonate (magnesite) has completely replaced olivine grains and the associated matrix.

Spinifex textures which occur in the basal parts of the ultramafic sequence are best described as the porphyritic type (Nesbitt 1971). Here coarse, equant, and tabular to elongate crystals of olivine occur in a matrix now marked by fine-grained chlorite and locally, fine-grained carbonate. The elongated crystals of olivine measure up to 2.5 cm in length and average 1.5 cm in width. This type of quenched olivine is not like the platy type of spinifex described by R.W. Nesbitt (1971) where individual olivine crystals form in parallel growths up to 1 m in length and commonly measure less than 1.0 mm thick. Spinifex-textures in flows in the upper part of the pile are best described as the platy type. Descriptions of this type of spinifex-texture have been well documented from flows in Munro Township (Pyke *et al.* 1973b).

Economic Geology

Previous accounts of the sulphide distribution at the Texmont Deposit describe a mineralized zone near the central part of the ultramafic sequence (Pyke 1975b; Naldrett and Gasparrini 1971; Leigh 1971). This zone can be traced over a length of about 679 m and a width of up to 58 m. The zone dips steeply east and trends somewhat obliquely (N20°E) to the general northerly trend of the enclosing ultramafic flows. This somewhat oblique trend of the mineralized zone may be more apparent than real due to considerable crossfaulting.

The sulphide mineralogy consists mainly of pentlandite and pyrrhotite with minor millerite, heazlewoodite, pyrite, and chalcopyrite. The sulphides are disseminated and occur as intercumulus "blebs" in cumulate-textured peridotite. Sulphides tend to occur in matrix areas between the larger crystals of olivine. Exceptions to this trend occur where sulphides are located between smaller olivine crystals. Generally, mineralized zones are extensively carbonatized. In diamond-drill hole 65-17, minor pentlandite is associated with massive pyrrhotite and pyrite in the footwall of the deposit south of line 4500N (Figure 6). This diamond-drill hole intersected massive sulphides at the footwall contact. Only seven diamond-drill holes intersected the contact, and most of these are located south of line 4500N.

At least six mineralized lenses have been identified within the Central Zone on the property: "A" (main) Zone, "B" Zone, "C" Zone, "D" Zone, South Zone and the North Zone. All but the North Zone are shown in Figure 6.

The "A" Zone is the main ore zone being developed at the mine, and is about 120 m long, averages 10 m wide, trends north, and dips about 75 ° to the east. The "C" zone is 3 to 9 m stratigraphically below the "A" Zone, and has been outlined from the surface to the 140 m level. The zone measures approximately 5.8 m wide.

The "B" and "D" Zones have been partly delineated on the 137 m level; little work has been done on their vertical continuity, although indications are that at least the "D" Zone extends to the 226.2 m level. The "B" and "D" Zones measure approximately 5.8 m and 4.8 m wide, respectively. The South Zone is the second largest ore zone on the property. This ore zone extends from the surface to at least 10 m, dips 75° east, has an indicated length of 120 m and an approximate horizontal width of 9 m.

The North Zone occurs about 210 m north of the "A" Zone; as yet little work has been done to delineate the mineralization. One diamond-drill hole intersection returned 1.04 percent nickel over 17 m at a depth of 286 m (Leigh 1971). Estimated ore reserves in the central mineralized zone (A,B,C, and D Zones) are 3,800,000 tons grading 1.0 percent nickel after dilution (Canadian Mines Handbook, 1976-77).

Diamond-drill logs, obtained from Texmont Mines Limited indicate that nickel sulphide mineralization is not strictly confined to the Central Zone, but is also distributed throughout the basal part of the ultramafic pile. The distribution of these sulphides together with those of the Central Zone has been contoured in Figure 7. The distribution of sulphides in the ultramafic pile (Figure 7) is arranged in concordant lenses about line 5000N near a gabbro dike which has intruded across the stratigraphy (Figure 6). This dike is located near a major cross fault and is in line with felsic volcanic breccia which outcrops in the footwall of the deposit. The arrangement of sulphides in concordant lenses about the vicinity of line 5000N is significant, in that it may delineate the feeder pipe to the system through which ultramafic lavas have extruded in the area of felsic breccia in the footwall. The feeder-pipe is not exposed on surface and may have been: 1) eroded away, or 2) exists at depth. This area near the footwall volcanic breccia was not diamond drilled during the devlopment of the property. The occurrence of a peridotite outcrop within the footwall near the felsic volcanic breccia (see Figure 6) lends support to this interpretation. The gabbro dike probably subsequently intruded this original zone of weakness marked by the proposed feeder-pipe near major faulting (Figure 8). Sulphides have been remobilized to a certain extent in the vicinity of post-ore faults (see Figure 7).

Section 4900N (Figure 9) illustrates the sulphide distribution towards the basal part of flows at the base of the ultramafic pile. Flow tops are indicated by the presence of spinifex texture and concordant gabbro-sills which have intruded along metasedimentary units representing stratigraphic intercalations in the ultramafic pile. These intercalated horizons of volcanogenic sediments and tuffs are generally mineralized with disseminated pyrrhotite, and locally contain massive clots of pyrrhotite and pyrite measuring up to 8 cm in diameter. Sulphide mineralization, as disseminated intercumulus blebs, is not restricted to the basal parts of flows but also occurs in the spinifex-textured parts of flows. Figure 10 illustrates the sulphide distribution in spinifex-textured parts of flows near the base of the ultramafic pile. Also present are pyrrhotite-pyrite colloform balls in a carbonaceous sedimentary rock marking an interflow boundary (Figure 10).

Section 4350N (Figure 11), also illustrates the distribution of disseminated sulphides near the base of the flow units and the association of sulphides with porphyritic-type spinifex texture which characterizes the flows at the base of the pile. When Eckstrand (1972) described the Texmont Deposit, section 4350N was also included in his report. It is important to point out a major difference in his

Figure 7–Map illustrating distribution of sulphide mineralization about Texmont Mines Limited property (assays after Texmont Mines Limited).

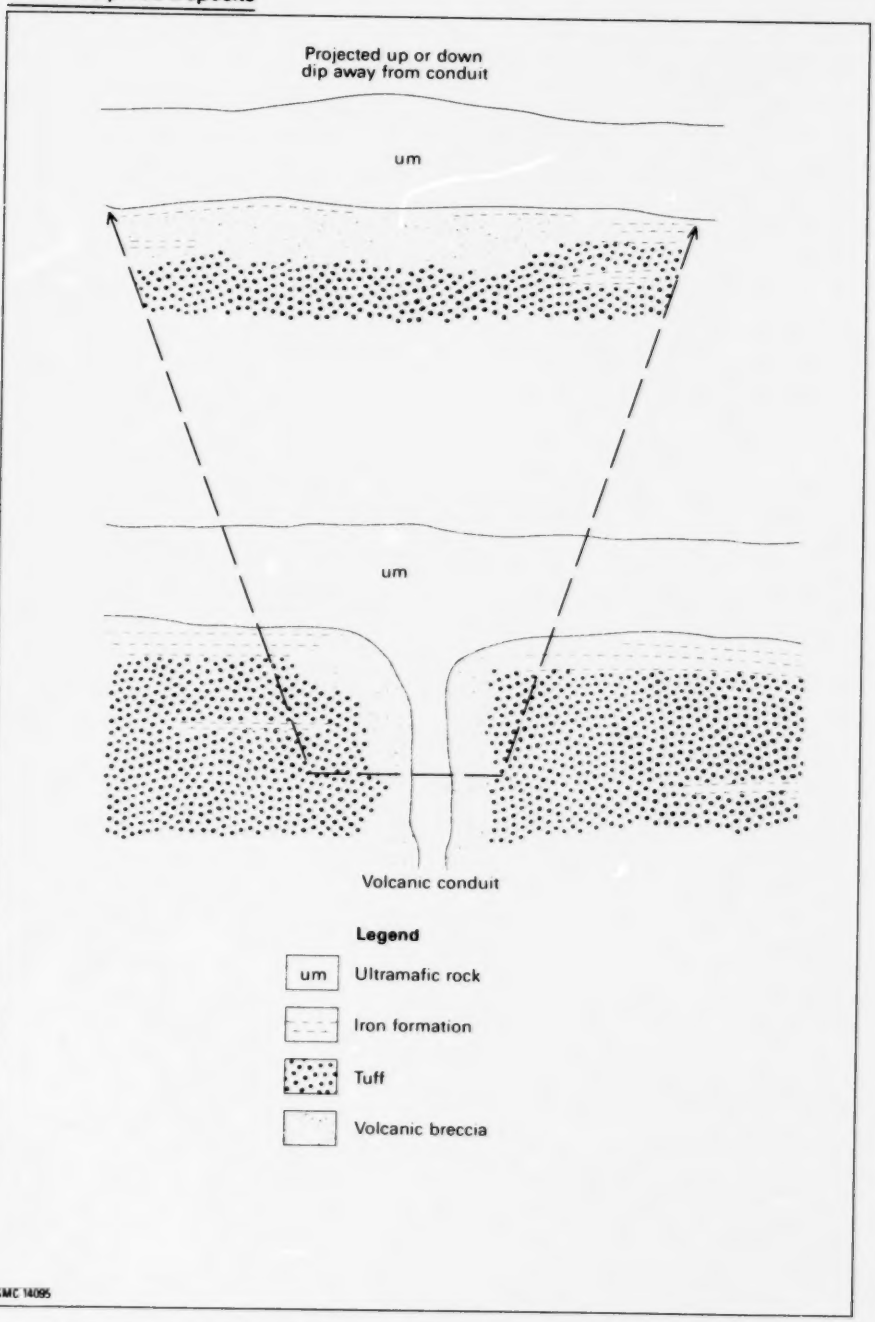

Figure 8–Proposed reconstruction of footwall at Texmont Mines Limited property.

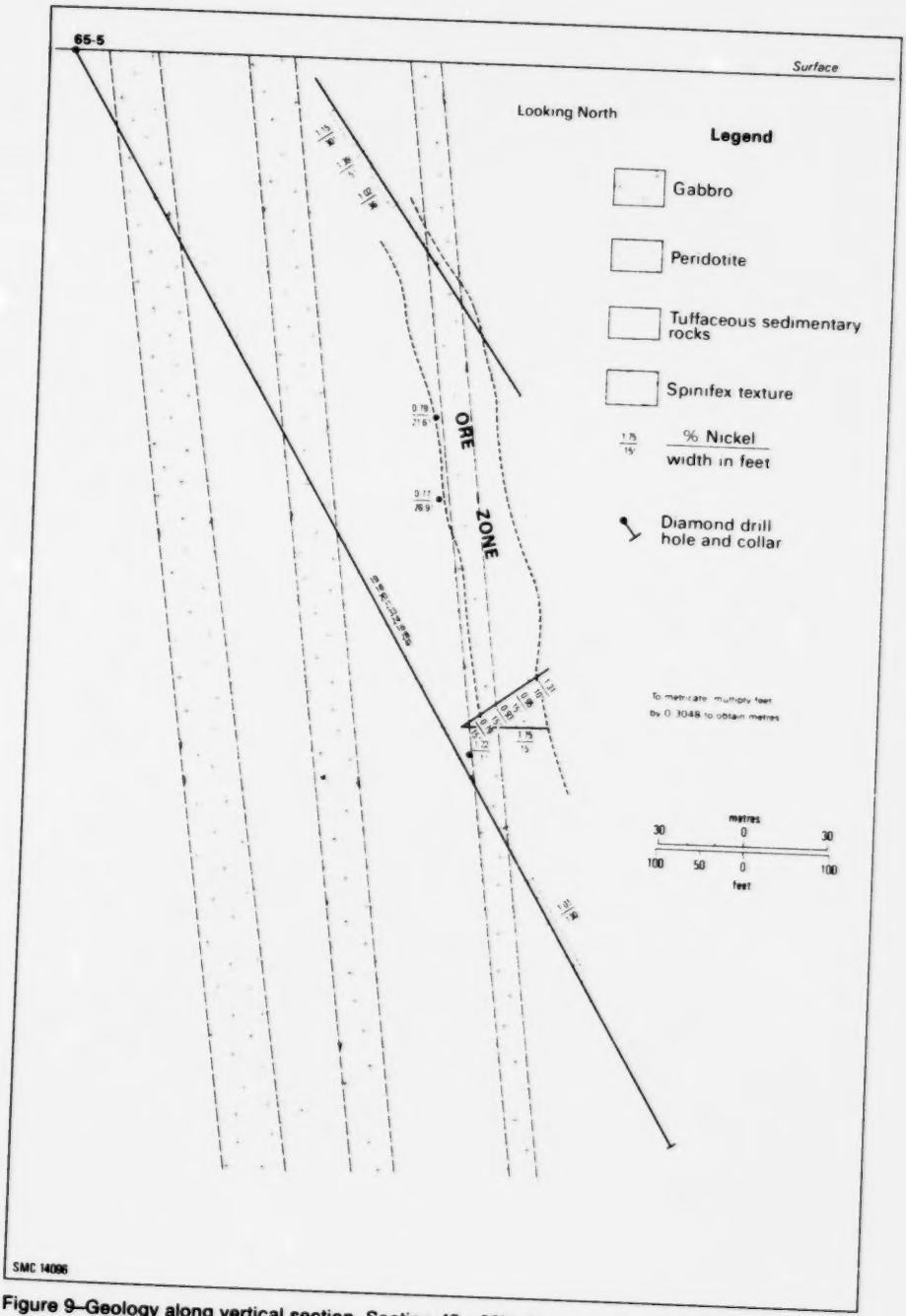

Figure 9–Geology along vertical section, Section 49+00N, Texmont Mines Limited property (assays from Texmont Mines Limited).

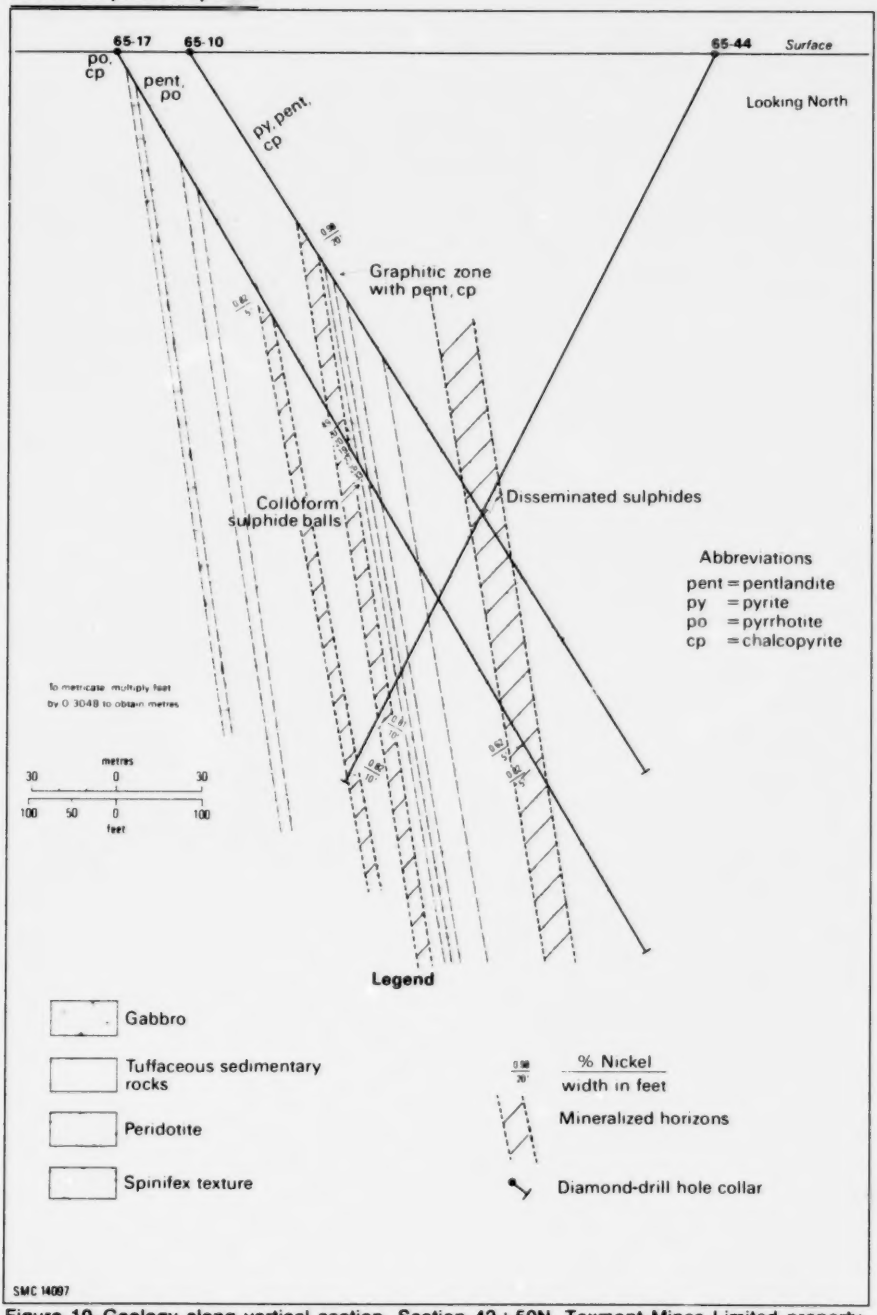

Figure 10–Geology along vertical section, Section 42 + 50N, Texmont Mines Limited property, (assays from Texmont Mines Limited).

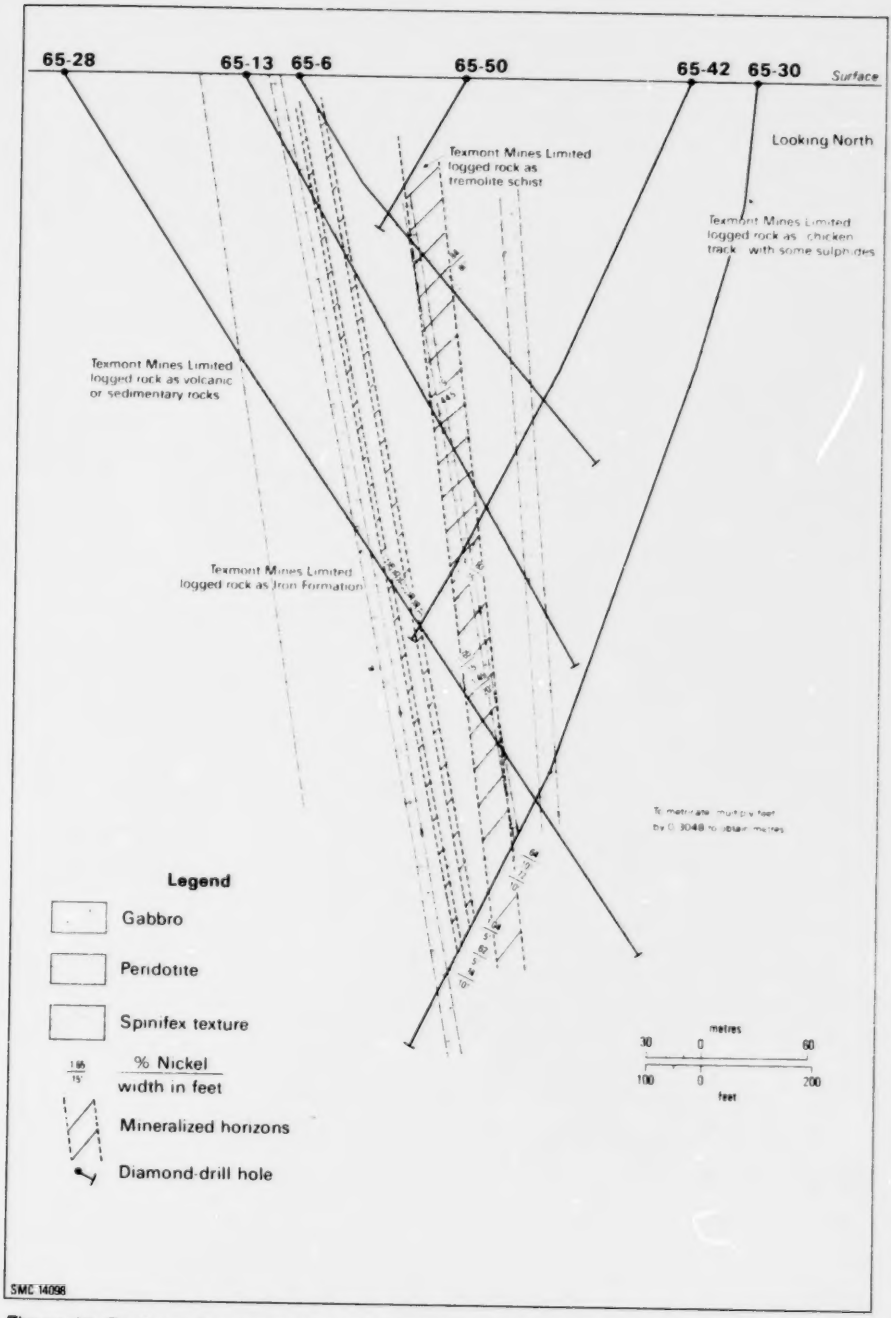

Figure 11–Geology along vertical section, Section 43+50N, Texmont Mines Limited property, (assays from Texmont Mines Limited).

section; spinifex textures near the base of diamond-drill holes 65-13 and 65-6 (section 4350N; Eckstrand 1972) were not observed during logging of the core. Instead, a gabbroic sill was observed at this location (Figure 11), with a diabasic texture but not the spinifex texture which is characteristic of ultramafic volcanic rocks. Spinifex in ultramafic rocks recorded in diamond-drill hole logs as "chicken-track" textures, occurs stratigraphically above this area as reported by Eckstrand (1972).

HART DEPOSIT

The Hart Deposit was not examined personally by the writer. Information concerning the deposit has been obtained from various published and unpublished reports.

Location

The Hart Deposit is located in the southeastern quarter of Eldorado Township, near the east boundary with Langmuir Township (see Figure 3). The deposit is at the southern margin of the Shaw Dome approximately 4.8 km southwest of the McWatters Deposit.

History and Previous Work

Detailed geological work was first done on the property in 1964, when Norlex Mines Limited optioned the property from L.N. Hart. Prior to this, only minor trenching had been undertaken. In 1965, Norlex Mines Limited completed electromagnetic and magnetic surveys and diamond drilled 13 holes totalling 1854.4 m (Canadian Mines Handbook and Assessment Files Research Library, Ontario Geological Survey, Toronto). Eleven of the diamond-drill holes were drilled to test an electromagnetic anomaly about 1000 m long. The anomaly is related to a sulphide-bearing iron formation and nickel mineralization occurring at the lower contact of an ultramafic body. Results of the diamond drilling proved to be inconclusive and the option was allowed to lapse.

In 1968, Paramaque Mines Limited acquired the property and subsequently diamond drilled six holes totalling 1959.0 m to further investigate the mineralized zone outlined by Norlex Mines Limited. At this time, the known depth of the mineralization was extended to about 300 m.

In 1969, McWatters Gold Mines Limited optioned the property from Paramaque Mines Limited and diamond drilled eight holes totalling 2440 m in length to further test the mineralized zone at depth. Results of this diamond drilling failed to delineate an economic deposit.

In 1969, the assets of McWatters Gold Mines Limited were purchased by Tontine Mining Limited (formerly North Rankin Nickel Mines Limited). In the

same year an agreement with Canadian Jamieson Mines Limited was announced, whereby that company would investigate previous work done on the property, and if feasible, bring it into production. At present, the deposit remains idle.

Brief descriptions of the deposit are reported by D.R. Pyke and R.S. Middleton (1970) and Pyke (1975a). The deposit is briefly discussed in a M.Sc. thesis recently completed by Muir (1975).

General Geology

The Hart Deposit is located at the base of an ultramafic sequence (Tisdale Group) overlying a felsic volcanic pile near the southern margin of the Shaw Dome (Figures 2 and 3). The base of the sequence is marked by serpentinized peridotite which is overlain by pyroxenitic flows, high magnesium basalts and intermediate metavolcanics (Muir 1975). This sequence forms part of the north limb of an easterly-plunging syncline (Pyke 1975a). The strata in the immediate vicinity of the deposit dip steeply to the southeast and trend east-northeast (Figure 12). Stratigraphic facing is to the south.

Footwall Rocks

The structural and stratigraphic footwall of the Hart Deposit consists of intermediate to felsic volcanic breccia and tuff and sulphide-bearing iron formation which locally overlies the breccia (Figure 12). The breccia consists of angular felsic fragments in a tuffaceous fine-grained matrix. Disseminated to massive pyrite and pyrrhotite extensively mineralize the footwall breccia and iron formation. The breccia part of the footwall is thickest beneath the nickel sulphide mineralization at the Hart Deposit (Figure 12). At this locality, the sulphide-bearing iron formation is thinner. At a vertical depth of 150 m the iron formation pinches out and the peridotite and volcanic breccia are in contact.

Host Rocks; Ultramafic Rocks

The serpentinized peridotite which hosts the sulphide mineralization is massive and is locally altered to chlorite, carbonate, and talc. Primary cumulate textures are not discernible in hand specimen. Spinifex textures are absent in the basal ultramafic unit which hosts the sulphide mineralization. However, pyroxene- and olivine-spinifex is reported to occur in pyroxenitic and ultramafic flows which stratigraphically overlie the basal ultramafic unit (Muir 1975). Margins of the basal ultramafic unit adjacent to the footwall agglomerate and iron formation are pyroxene-rich as is reflected by element profiles across the contact (Muir 1975). Magnesia content increases stratigraphically upward away from the footwall contact whereas alumina, lime, and the alkalies increase toward the contact.

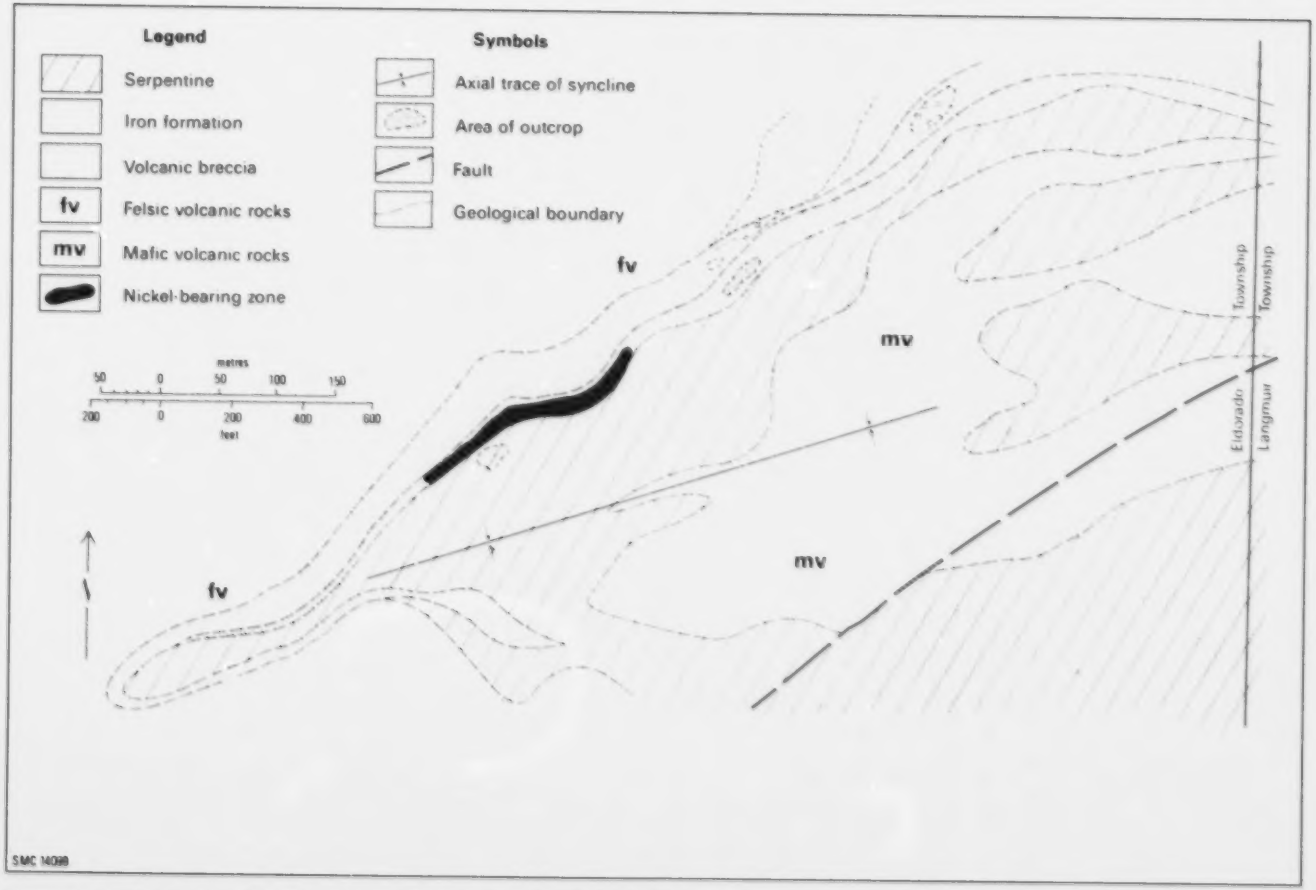

Figure 12–Geological plan of Hart Nickel Deposit (modified after Pyke 1975a).

Economic Geology

A mineralized zone, measuring 200 m long and up to 9 m wide, occurs along the footwall peridotite contact overlying the pyroclastic rocks and sulphide iron formation (Figure 12). The zone plunges about 50° southeast, paralleling the plunge of broad open crossfolds on the northern limb of the main syncline (Pyke 1975a). Irregularly shaped and discontinuous pods of mainly massive iron sulphides occur along the contact between the volcanic breccia, iron formation, and peridotite contact. These massive pods are overlain by bleb or disseminated sulphides representing original net-textured sulphides.

The nickel sulphide mineralization is spotty and sub-economic, although grades of up to 2.0 percent nickel over a length of 3.6 m have been reported in diamond drilling (Pyke 1975a). The sulphide mineralogy consists of pyrite, pyrrhotite, pentlandite, and minor chalcopyrite. Subhedral to euhedral grains of magnetite are generally associated with the sulphides forming up to 2 modal percent by volume of the rock. The pyrite generally forms coarse subhedral crystals in a fine-grained pyrrhotite host, pentlandite occurs as irregularly-shaped blebs in the pyrrhotite and at pyrite-pyrrhotite grain boundaries (Pyke 1975a). Minor pentlandite occurs locally in the iron formation and volcanic breccia (Muir 1975).

McWATTERS DEPOSIT

Location

The McWatters Deposit is located in Langmuir Township about 2.4 km east of the west township boundary and approximately 4 km north of the south boundary (see Figure 3). The deposit is situated approximately 4 km southwest of the Langmuir Deposit.

History and Previous Work

The property was first examined in 1947 when Dominion Gulf Company conducted an airborne magnetometer survey. In 1961, McWatters Gold Mines Limited, in partnership with Quebec Manitou Mines Limited, acquired a group of 54 unpatented claims covering 890 ha in Langmuir Township. During the year, 13 diamond-drill holes (1067.4 m) were drilled to investigate anomalies at the McWatters property previously indicated by magnetometer surveys (Assessment Files Research Office, Ontario Geological Survey, Toronto).

The last diamond-drill hole drilled, centred in a magnetic anomaly 1030 m long and 60 m to 120 m wide, intersected 60.6 m of mineralization averaging 0.428 percent nickel (Assessment Files Research Office, Ontario Geological Survey, Toronto). Of this section, 9.8 m assayed 0.65 percent nickel. In 1962, a further 24 diamond-drill holes totalling 2600 m were drilled. This work indicated a small sub-economic nickel deposit.

In the fall of 1964, McWatters Gold Mines Limited decided to resume diamond drilling on the claims to further test the known mineralized zone for vertical continuity and possible improvement of grade at depth. Twenty-five diamond-drill holes totalling 801.8 m were completed before work on the property ceased. This diamond drilling delineated an upper and lower zone to the deposit, but no significant mineralization was located beneath or along the strike of the deposit.

In 1967, an exploration programme of deep penetration electromagnetic surveying, followed by 395.6 m of diamond-drilling, was completed to test a segment of the property located near or on the strike of the original nickel discovery. This work failed to indicate any economic mineralization.

Under the terms of an agreement dated February 23, 1970, the assets of McWatters Gold Mines Limited were purchased by Tontine Mining Limited (formerly North Rankin Nickel Mines Limited). In September 1970, an agreement with Canadian Jamieson Mines Limited was announced, whereby that company would investigate previous work on the property, and if warranted bring it into production. The interest of Tontine Mining Company in the property was 82.5 percent and that of Quebec Manitou Mines Limited was 17.5 percent.

In 1971, Canadian Jamieson Mines Limited conducted geophysical surveys, metallurgical testing, and diamond drilling on the property. Results of this work were inconclusive.

Brief descriptions of the McWatters Deposit include accounts by Wilson *et al.* (1969), Pyke (1970), Pyke and Middleton (1970), Eckstrand (1972; 1973) and more recently Muir (1975).

General Geology

At the McWatters Deposit, a locally discordant ultramafic sill-like body has intruded intermediate to felsic pyroclastic rocks of the Deloro Group (Figure 13). The ultramafic body, which measures 48 m thick, strikes northeast and dips steeply to the southeast. The body has been delineated to a vertical depth of 150 m. Stratigraphic facing in the vicinity of the deposit is not well established due to poor outcrop exposure and considerable folding about the margins of the Shaw Dome. Structurally, the base of the ultramafic body is separated from an underlying ultramafic unit by a concordant lens-shaped body of porphyritic rhyodacite (Figure 13). Muir (1975) described this porphyritic unit as a massive to amygdaloidal metavolcanic.

Host Rocks; Ultramafic Rocks

The ultramafic rocks are invariably serpentinized and locally altered to talc, chlorite, and carbonate. Massive and cumulus-type textures are locally preserved and are best developed near the centre of the body where pyroxene occurs as an intercumulus phase. Significant amounts of intercumulus amphibole and pyrox-

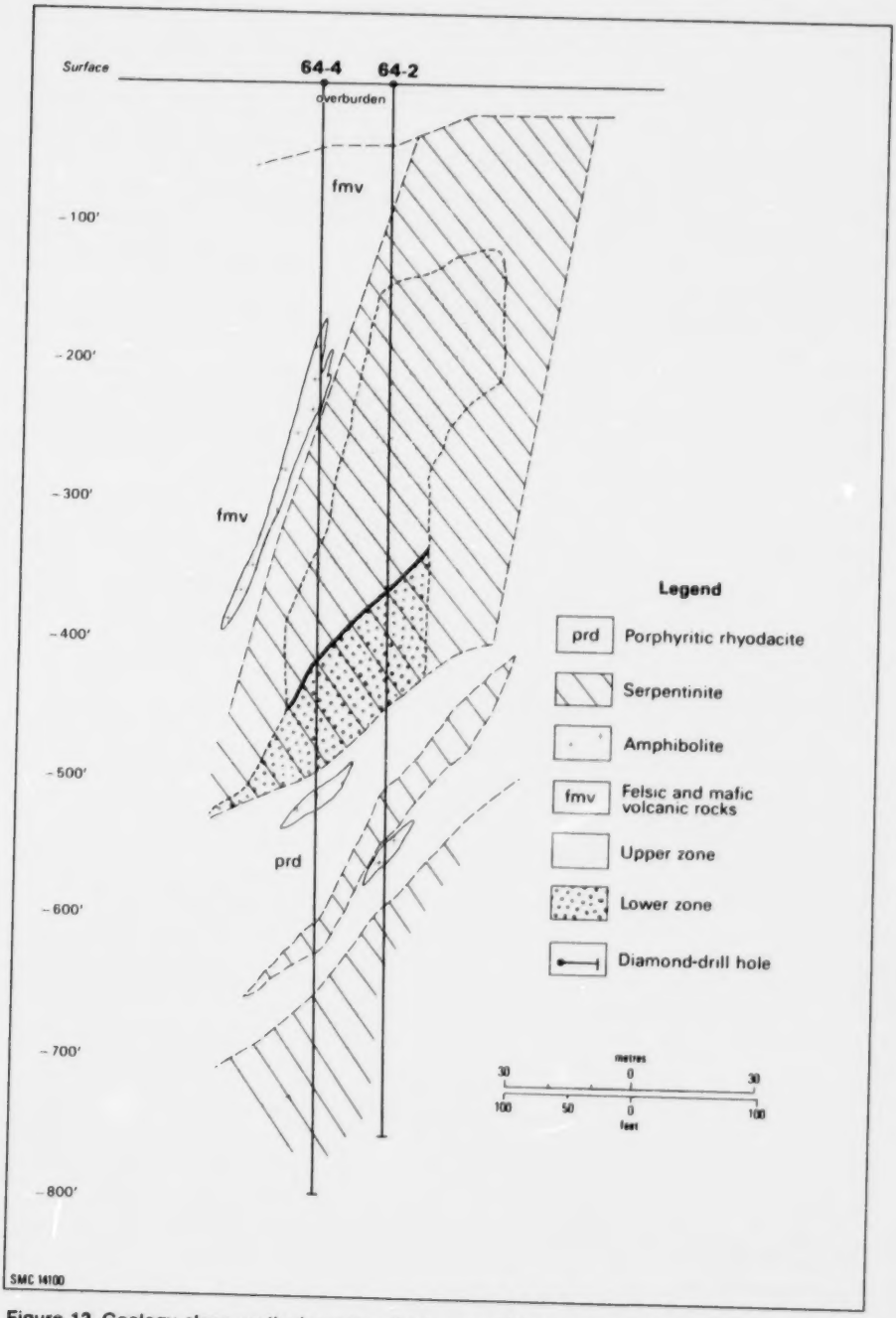

Figure 13–Geology along vertical section, Section 1+00N, McWatters Nickel Deposit (modified after Pyke 1970a).

ene occur near the margins of the body. Spinifex textures have not been recognized in the ultramafic rocks which host the sulphide mineralization, however, Eckstrand (1972) reported the presence of spinifex textures in ultramafic rocks which underlie the porphyritic ryhodacite unit in Figure 13. By plotting element profiles across the body, Wilson *et al.* (1969) have documented the sill-like nature of the body where magnesia is concentrated at the centre and alumina, lime, and the alkalies are concentrated at the edges of the body.

Country Rocks

Country rocks consist generally of massive to fragmental intermediate to felsic metavolcanics. Felsic volcanic breccia and tuff predominate in the vicinity of the ultramafic body which hosts the sulphide mineralization. Fragments are of variable size with long axes ranging up to 20 cm in length. The fragments are generally angular and loosely packed in a tuffaceous matrix which is extensively mineralized by disseminated to massive pyrite and pyrrhotite. Thin units of carbonaceous sedimentary rock as much as 2 m thick occur throughout the breccia and massive metavolcanics. Spheroidal pyrite with colloform textures together with thin bands of pyrite occur in the carbonaceous horizons.

Economic Geology

Nickel sulphide mineralization occurs in two zones, an upper and lower zone near the centre of the ultramafic body above the porphyritic rhyodacite unit (Figure 13). Together, the zones form a deposit 90 m long and 15 m wide. Estimated tonnages and grades include 477,768 tons grading 0.73 percent nickel for the upper zone and 165,700 tons grading 1.92 percent nickel for the lower zone (Assessment Files Research Office, Ontario Geological Survey, Toronto). The main sulphides present are in decreasing order of abundance, pyrite, millerite, pentlandite, and chalcopyrite. Pyrrhotite and violarite occur in minor amounts. The principal oxide minerals are magnetite and chrome spinel. The chrome spinel occurs as large euhedral grains, generally rimmed by magnetite. The magnetite, in addition to forming rims around the chrome spinel, is abundant as disseminated grains in the silicates.

Disseminated-type sulphide is the predominant form of the mineralization in the upper zone with minor stringer and bleb sulphides occurring locally in the lower zone. Bleb sulphide or clots of pentlandite, pyrite, and millerite generally occur in shear zones or areas of extensively altered peridotite. Locally, in the lower zone, irregularly shaped fragments of peridotite are in a matrix of massive to disseminated sulphides. This type of mineralization occurs in zones measuring up to 1.5 m thick and appears to have been formed by tectonic deformation and the remobilization of sulphides.

Zones of massive sulphides, measuring as much as 2.0 m thick occur locally along the structural footwall of the lower mineralized zone adjacent to the porphyritic rhyodacite unit. The ore has a granular texture consisting of recrystallized pyrrhotite, pentlandite, and pyrite.

Disseminated sulphide mineralization (Muir 1975) occurs in the lowermost ultramafic rocks at the base of diamond-drill holes 64-2 and 64-4 (Figure 13). The relationships of these sulphides to the main zones of mineralization is not known.

ALEXO DEPOSIT

Location

The Alexo Deposit is located in Dundonald Township, approximately 50 km northeast of Timmins, Ontario (Figure 3). The shaft site is located on lot 1, concession III, in Dundonald Township, close to the boundary with Clergue Township.

History and Previous Work

The Alexo Deposit was discovered in 1907 by a prospector named Alex Kelso (Baker 1917). A diamond drilling option was taken by the Canadian Copper Company, but after an apparently unsatisfactory investigation, the option was dropped. The owners (Alexo Mining Company) decided to operate the property themselves, and between 1912 and 1919 approximately 52,000 tons of ore, averaging approximately 4.5 percent nickel and 0.5 percent copper, were mined and shipped to the Mond Nickel Company in Sudbury (Assessment Files Research Office, Ontario Geological Survey, Toronto). Operations and development ceased in 1919 when diamond drilling failed to indicate any extension of the ore shoot downward, and the narrower and lower grade material along strike did not constitute ore.

In 1943 and 1944, Harlin Nickel Mines Limited operated the property, and recovered several thousand tons of ore left by earlier operators on surface and in pillars underground. Ontario Nickel Mines Limited secured an option on the property in 1952. However, exploratory work failed to delineate any new ore bodies. In 1952, the Alexo property was purchased from the Alexo Mining Company by Noranda Mines Limited. In 1958, Noranda Mines Limited drilled 15 diamond-drill holes in an effort to delineate ore further along strike from the shaft area. The last work completed by Noranda Mines Limited involved a ground magnetometer survey in the winter of 1976.

Considerable scientific attention has been directed toward the Alexo Deposit in the past. Brief descriptions of the deposit include work by A.P. Coleman (1910; 1913); W.L. Uglow (1911a,b); and H.B. Baker (1917). More recent studies include a M.Sc. thesis by H.C. Lowther (1950) and part of a Ph.D. study by Naldrett (1964). Ideas concerning the genesis of the deposit are reported by Naldrett (1966; 1973), Kilburn *et al.* (1969), and Pyke and Middleton (1970).

General Geology

The ultramafic body at the Alexo Deposit occurs as a concordant lens, with a dunitic core and pyroxene-rich peridotitic margins atop a series of magnesium-rich basalts and intercalated hyaloclastite. The unit measures 70 m thick and approximately 500 m long, strikes west southwest and dips 80° northwest parallel to the strike of the footwall lavas. The unit appears to be stratigraphically equivalent and correlative with pyroxene-rich lenses (Figure 14) which occur in pillow lavas further to the west on top of the Dundonald Sill, a differentiated peridotite-gabbro body (Naldrett and Mason 1968). Locally, semi-concordant sills of gabbro intrude both margins of the Alexo body.

Host Rocks; Ultramafic Rocks

Petrological information concerning the Alexo body has been obtained from diamond-drill core as surface exposure is lacking due to extensive drift cover. The dunitic part of the body is marked by cumulate and adcumulate textures consisting of 80 to 95 percent by volume serpentine pseudomorphous after equant- to oval-shaped olivine grains which range between 0.5 and 1.0 mm in diameter. Olivine also occurs as elongate grains measuring up to 2.5 mm in length. Individual crystal boundaries are generally rimmed by fine-grained chlorite (after devitrified glass), feathery pyroxene, magnetite, chromite, and subhedral to skeletal clinopyroxene. One small patch of spinifex texture was observed near the centre of the body where elongate olivine blades are arranged in subparallel sheaths measuring 2 cm in length.

Margins of the body are marked by a significant increase in the content of clinopyroxene, which may form up to 30 percent of the rock. Here, clinopyroxene occurs as anhedral to skeletal grains and together with fine-grained chlorite (after devitrified glass) forms 75 percent of the rock by volume. In this specimen, hyaloclastite is intimately interfingered with the pyroxene-rich rock. Elongate laths of altered plagioclase occur in random orientation with bladed olivine at the margin of one specimen from the margin.

Footwall Rocks

Pillows in the footwall basalts average 30.0 cm in diameter and locally contain varioles measuring up to 1.5 mm in diameter. In outcrop, the lavas are pale grey-green and have a distinct "bleached-like" appearance. This would appear to be due to hydrothermal alteration, possibly related to the emplacement of the nickel ore and the associated ultramafic rocks (see section on "Geochemistry"). Pillow selvages are not well developed and are generally absent. Thin zones of hyaloclastite are intercalated with the volcanic rocks particularly near the peridotite-volcanic rock contact. In diamond-drill core, thin concordant zones of peridotite (17.8 cm thick) were observed in hyaloclastite near the footwall of the deposit.

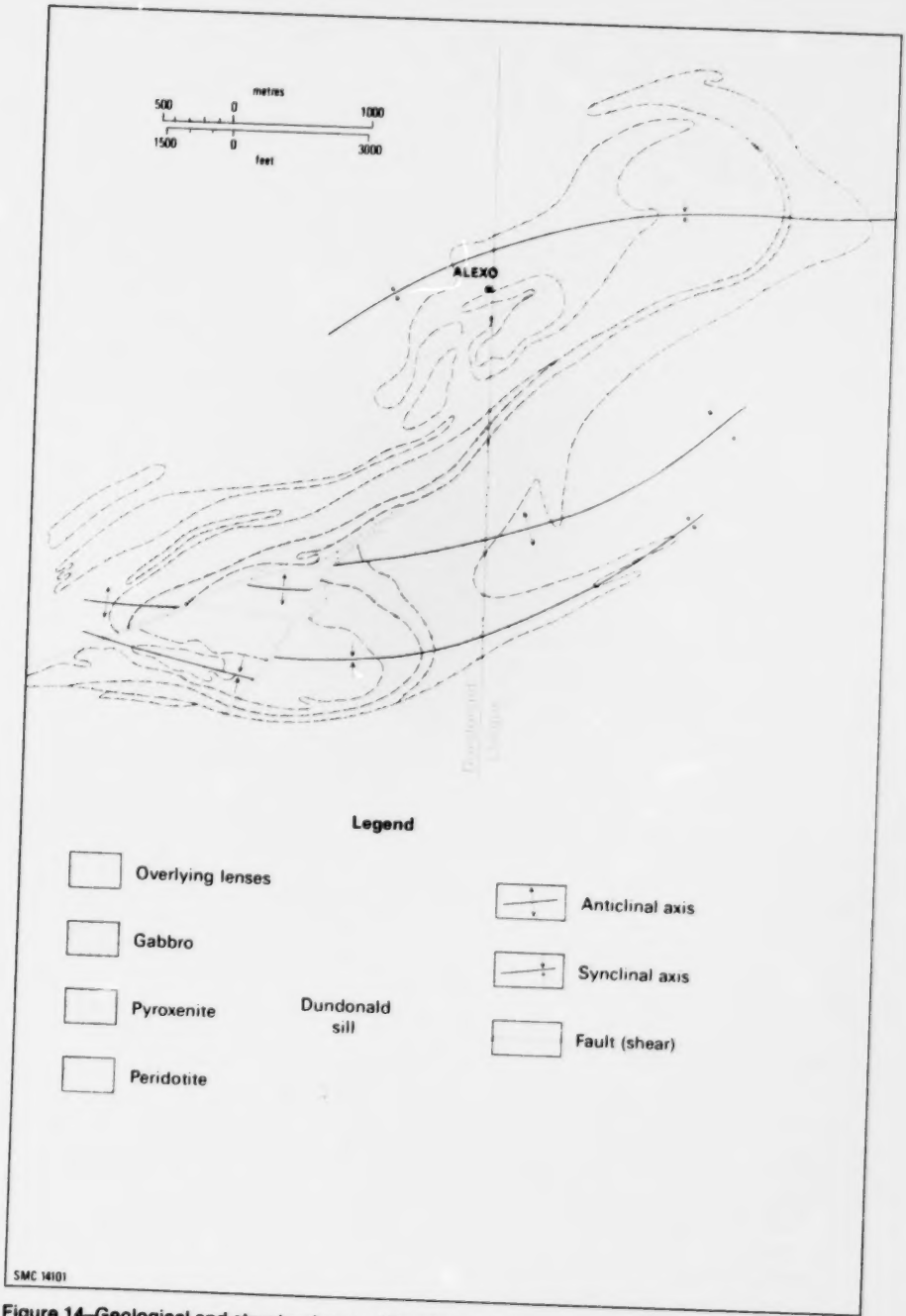

Figure 14–Geological and structural map of Dundonald-Clergue Area (modified after Naldrett and Mason 1968).

Thin section examination reveals that the basalts consist of minute laths of plagioclase and pyroxene in a fine-grained matrix of chlorite and secondary amphibole. Hyaloclastite consists of irregularly shaped and irregularly sized shards and fragments of devitrified glass in a matrix of fine-grained tuffaceous material. Fragments are characterized by complete chilled margins.

Footwall volcanic rocks generally contain disseminated pyrrhotite, pyrite, and minor chalcopyrite.

Economic Geology

Massive to disseminated ore is located in shallow embayments along the footwall contact (Figure 15). Sulphide minerals consist of pyrrhotite, pentlandite, heazelwoodite, chalcopyrite, and violarite in that order of decreasing abundance. Minor amounts of magnetite are associated with the massive ore. Grades of 4.5 percent nickel and 0.5 percent copper are reported for the 52,000 tons of ore mined (Baker 1917). The massive ore zone measures between 5 cm and 3.0 m thick occurring on top of the basal pyroxene-rich margin or against the footwall volcanic rocks. Locally, massive sulphides penetrate into the footwall volcanic rocks up to a distance of 5.0 m (Naldrett and Gasparrini 1971). Massive sulphides are in sharp contact with the overlying disseminated ore, which consists of a continuous network of sulphides in peridotite (Photo 10). This texture is called "net-texture" (Naldrett 1973). Net-textured sulphides occur up to a distance of 4.0 m from the massive ore contact. Net-textured sulphides also occur locally in the basal pyroxene-rich peridotite underlying the massive ore zone. Here, the sulphides do not form a continuous network, but are concentrated into distinct layers, 2 to 5 cm wide paralleling the strike of the host rocks. These mineralized layers of net-textured sulphides are separated by pyroxene peridotite which is barren of sulphides. In the disseminated or net-textured sulphides it is not uncommon to find olivine and/or pyroxene crystals partly or completely replaced by pyrrhotite or pentlandite. In certain specimens relict olivine grains are marked by cores of pyrrhotite mantled by pentlandite. Minute blebs of pyrrhotite are recognized in some olivine grains. The distribution of sulphide in rocks partly mineralized by net-textured sulphides is random, but locally sulphides appear to have concentrated between the coarser crystals of olivine in large matrix areas.

Massive ore is fine grained and in thin sections is characterized by a granular mosaic of re-crystallized pyrrhotite. Pentlandite typically occurs as anhedral grains between grains of pyrrhotite and rarely occurs as exsolution lamellae in the latter. Euhedral grains of pentlandite also form large "eyes" in the massive ore measuring up to 2 mm in diameter. Magnetite occurs as subhedral crystals or as fine hair-like veins that cut both pyrrhotite and pentlandite. Chalcopyrite is not common in the nickel ore, but where present it is usually associated with pentlandite embaying pyrrhotite grain boundaries. Thin bands of chalcopyrite measuring less than 2 mm thick occur at the base of the massive ore. Relict olivine grains which have been replaced by magnetite with minute inclusions of chalcopyrite, pentlandite, or pyrrhotite occur locally in crude layers near the top of the ore.

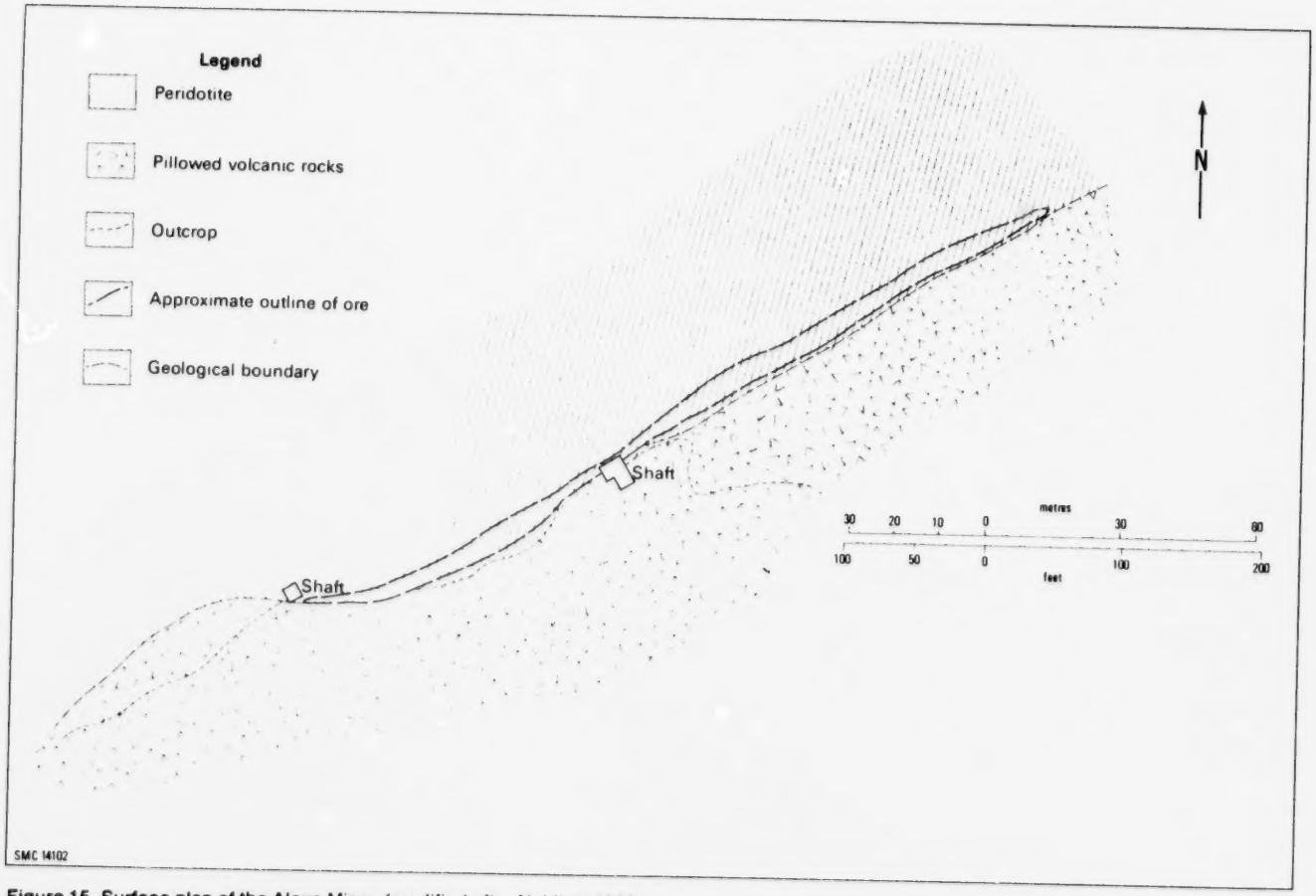

Figure 15–Surface plan of the Alexo Mines (modified after Naldrett 1966).

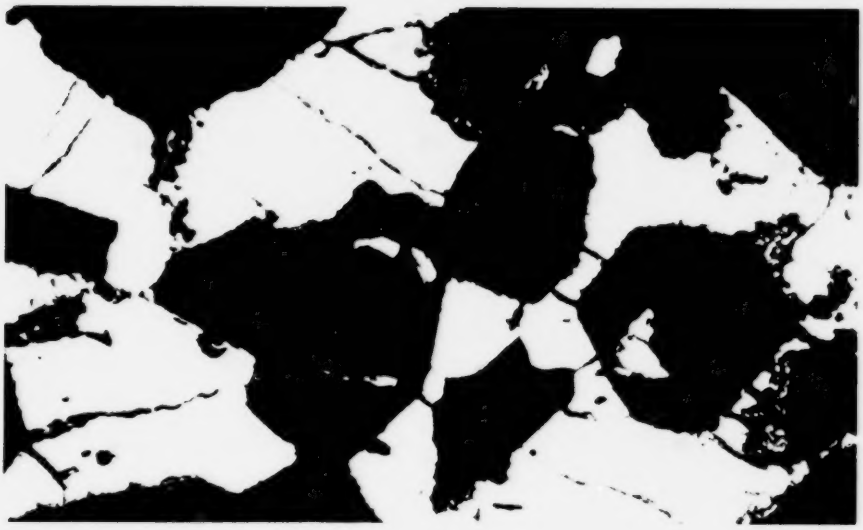

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Photo 10–Pentlandite and pyrrhotite occupy the matrix area between equant grains of serpentinized olivine. Field of view is 3.3 mm. Specimen J75-37, Alexo Deposit.

Sporadic concentrations of pyrrhotite and minor pentlandite are randomly distributed throughout the entire body, and although not identified, heazlewoodite is reported to occur in peridotite above the ore zone (Naldrett 1966). The distribution of heazlewoodite is due to later effects of serpentinization (Naldrett 1973). Pyrrhotite is initimately associated with the occurrence of spinifex textures previously described. Here, pyrrhotite forms the matrix areas between elongate grains of olivine. Eckstrand (1973) also reports the occurrence of sulphide-bearing spinifex-textured rock in a specimen from the Alexo dump.

SOTHMAN DEPOSIT

Location

The Sothman Deposit is located in the southeast portion of Sothman Township, 72 km due south of Timmins, Ontario.

History and Previous Work

The deposit was first discovered in 1950 when prospectors working for Dominion Gulf Company located nickel-bearing float on the property during the examination of an aeromagnetic anomaly. Between 1950 and 1953, the Dominion Gulf Company conducted geological and geophysical surveys eventually diamond drilling 37 holes totalling 5002.7 m (Assessment Files Reseach Library, Ontario Geological Survey, Toronto). This work by Dominion Gulf Company delineated a sub-economic mineralized zone measuring 48 m long, 2 m wide, and 84 m deep, and averaged 1.40 percent nickel with minor copper (Assessment Files Research Office, Ontario Geological Survey, Toronto).

The deposit remained idle until 1956 when Beauvale Mines Limited, a subsidiary of Kirkland Minerals Corporation Limited, optioned the property and subsequently completed a geological survey and diamond drilling programme. Results of this work failed to delineate further ore and the deposit was abandoned.

In 1966, the deposit was optioned by Falconbridge Nickel Mines Limited, who subsequently allowed the option to lapse after exploratory diamond drilling failed to delineate additional ore. The deposit is currently owned by Sothman Mines Limited, which is controlled by Falconbridge Nickel Mines Limited (Canadian Mines Handbook, 1976-1977).

Brief descriptions of the deposit are reported by E.M. Abraham (1953), E.P. Schneeberg (1969), Kilburn *et al.* (1969), Naldrett and Gasparrini (1971) and J.J. Watkins (1972).

General Geology

The Sothman Deposit is located on the south limb of an arcuate zone of mafic-ultramafic rocks which outlines the periphery of an anticlinal domal structure covering the area bounded by Halliday, Sothman, and Midlothian Townships (Pyke, Ayres, and Innes 1973). The structure which is locally called the "Halliday Dome" plunges steeply to the west.

Dacitic to rhyolitic metavolcanics of the Deloro Group occupy the central area of the dome; they are interstratified with and surrounded by intermediate metavolcanics (Bright 1970). Concordant ultramafic sills, flows, and peridotite-gabbro bodies, possibly correlative with those of the Timmins area, form an arcuate zone about the south, west, and northwest margins of the Halliday Dome. The zone is tightly folded in the vicinity of the Sothman Deposit. However, aeromagnetic data indicates that the peridotite which hosts the Sothman Deposit is stratigraphically equivalent and continuous with the remainder of the zone outlining the western and northwest margins of the dome. Abraham (1953) described the local presence of "chicken-track" or spinifex textures in peridotite about the margins of the dome, indicating the probability of extrusive flows.

Host Rocks; Ultramafic Rocks

The deposit is located in a concordant sill-like ultramafic body which measures 4.0 km long, 200 m thick, strikes east, and dips steeply southward. The body consists of a dunitic core with pyroxene-rich peridotitic margins. Primary cumulate textures are locally preserved in diamond-drill core from the centre of the body, whilst its margins are marked by cumulate textures with "intercumulate" and poikilitic clinopyroxene. Serpentinized olivine forms equant crystals which measure 1.0 mm in diameter. No spinifex textures were observed in outcrop or diamond-drill core by the author. However, Schneeberg (1969) described local occurrences of elongate olivine crystals which measure as much as 4.0 mm in length.

Small gabbro dikes and sills intrude the ultramafic body.

Footwall Rocks

Footwall rocks consist of intermediate to felsic volcanic rocks, breccia, and minor tuff. Locally, the basalts contain amygdules which measure as much as 3 cm in diameter. The volcanic rocks are mineralized with disseminated pyrite, pyrrhotite, and minor colloform-textured marcasite. Minute grains of sphalerite occur locally in the volcanic rocks.

The original intergranular texture of the volcanic rocks is relatively well preserved and no recrystallization is evident in thin section. However, the volcanic rocks are moderately bleached near the contact of peridotite and the volcanic rocks suggesting some type of alteration.

Economic Geology

Nickel sulphide mineralization occurs as net-textured ore (Photo 11) along embayments in the footwall (Figure 16). Watkins (1972) reported that the sulphides are concentrated into three separate lenses along the footwall contact. These lenses vary in width from several metres to 10.7 m, have a known horizontal length of 360 m and persist to a depth of 180 m where they pinch out. In places, significant amounts of mineralization occur (3 m to 4.6 m) above the basal contact of the ultramafic body. The deposit is estimated to contain 210,000 tons averaging 1.29 percent nickel with an additional 400,000 tons of lower grade ore (Assessment Files Research Office, Ontario Geological Survey, Toronto).

The sulphide mineralogy consists of pyrrhotite, pentlandite, violarite, and chalcopyrite; these minerals are listed in order of decreasing abundance. Pentlandite generally occurs as exsolution lamellae in pyrrhotite or as minute anhedral grains interstitial to olivine. Magnetite occurs as minute grains in olivine crystals and as anhedral grains about recrystallized pyrrhotite.

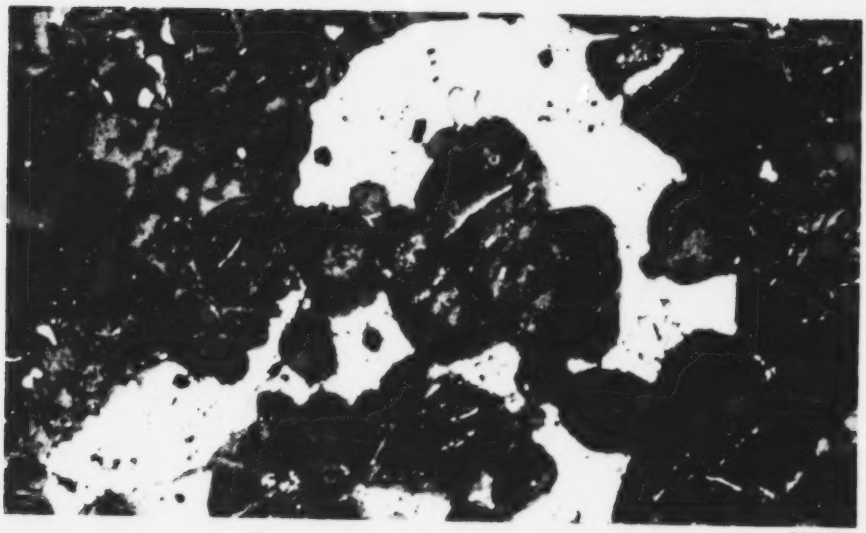

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Photo 11–Recrystallized pentlandite, pyrrhotite, and magnetite form a net-texture about serpentinized olivine grains, Specimen J75-313, Sothman Deposit. Field of view is 3.3 mm.

GEOCHEMISTRY OF DEPOSITS

Host Rocks

A total of 49 host rock analyses from the various deposits was obtained. Of these analyses, thirty-eight were obtained from published or unpublished sources; the remainder were analysed by the Geoscience Laboratories, Ontario Geological Survey, and are listed in Table 2.

These analyses indicate that ultramafic host rocks from the Langmuir, Texmont, McWatters, Hart, Alexo, and Sothman Deposits belong to the komatiitic magma suite as defined by Arndt *et al.* (1976). In a plot of Al_2O_3 versus $FeO/(FeO+MgO)$ where iron is calculated as total iron, all but two analyses from the Sothman Deposit, fall on the komatiitic side of the sloping line (Figure 17). In a graph of MgO versus TiO_2 the rocks have a low TiO_2 content for any given value of MgO as do all rocks belonging to the komatiitic suite (Figure 18).

In an $MgO\text{-}CaO\text{-}Al_2O_3$ diagram, MgO makes up between 50 and 95 percent of the toal $MgO+CaO+Al_2O_3$ content of the rocks reflecting their komatiitic affinity (Figure 19). The straight line trend away from the MgO apex indicates that fractionation is controlled by removal of a mineral rich in MgO and containing very small, and equal amounts of CaO and Al_2O_3; in this case the mineral was probably olivine.

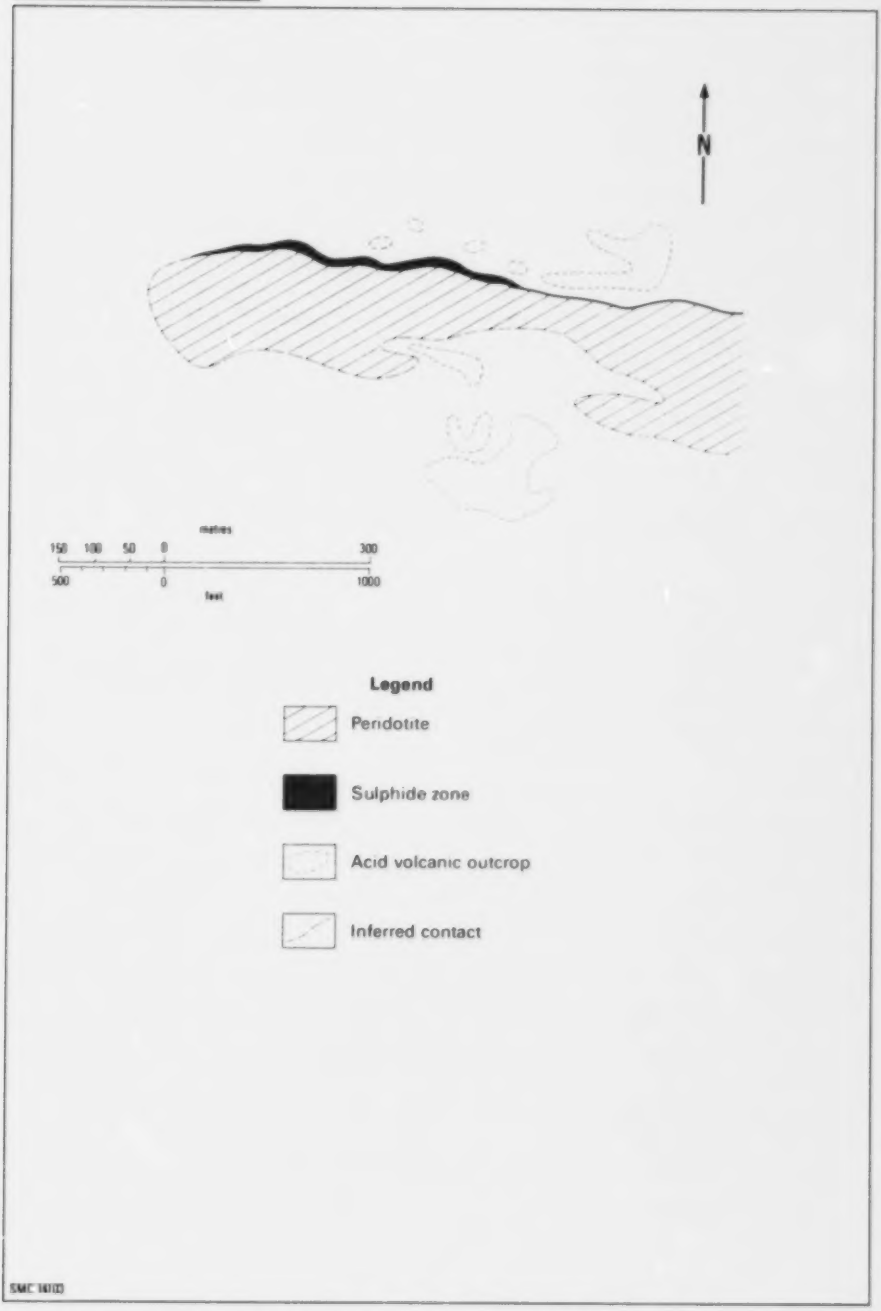


Figure 16–Geological plan of the Sothman Deposit (modified after Naldrett and Gasparrini 1971).

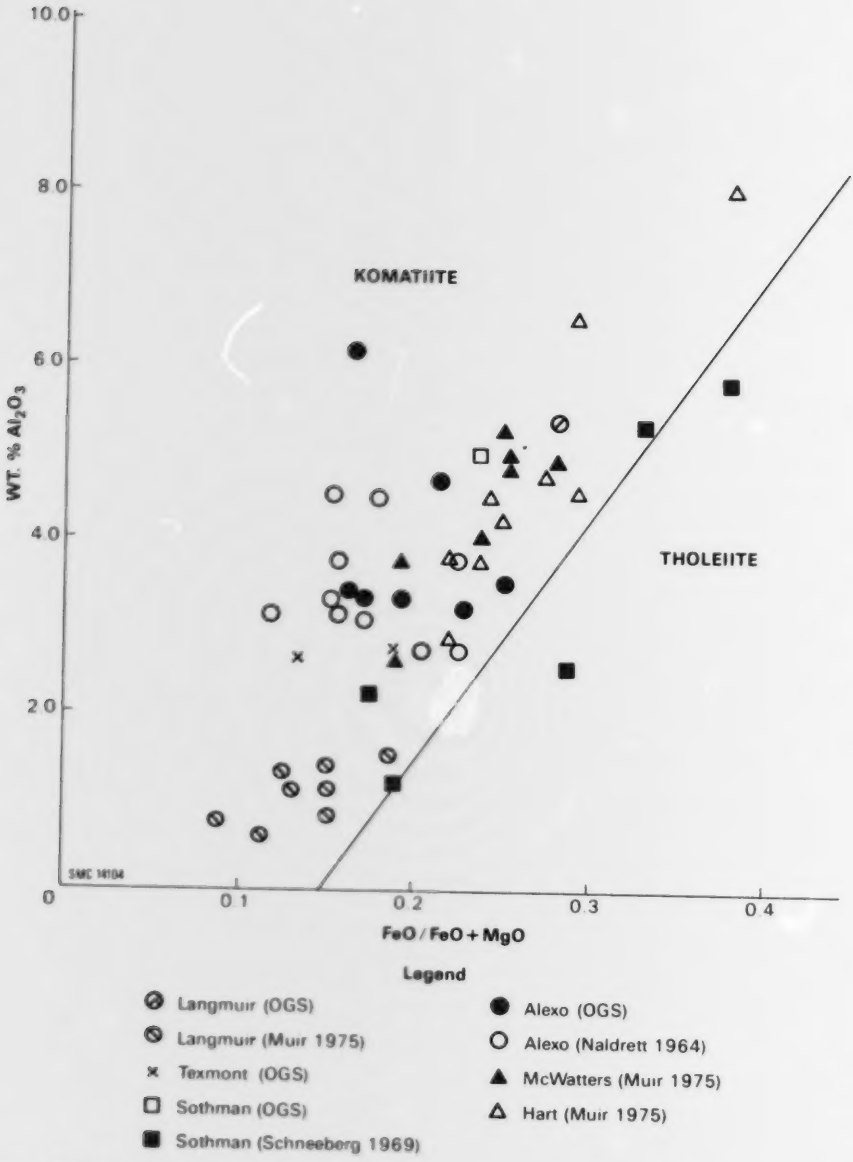


Figure 17–Weight percent Al_2O_3 versus FeO/FeO + MgO diagram for selected nickel deposits in the Abitibi Belt (total iron as FeO).

TABLE 2 | CHEMICAL ANALYSES OF ROCKS FROM THE VARIOUS NICKEL DEPOSITS.

Sample Number	J75-15		J75-18		C76-241		J75-107		J75-108		J75-96	
SiO_2	38.90	(43.50)**	59.80	(62.20)	51.10	(54.65)	40.30	(45.20)	35.40	(40.40)	61.50	(62.69)
Al_2O_3	4.84	(5.41)	15.50	(16.10)	13.90	(14.86)	2.15	(2.41)	2.11	(2.41)	16.00	(16.31)
FeO*	12.69	(13.58)	6.27	(6.52)	10.09	(10.79)	6.19	(6.66)	12.07	(8.00)	5.97	(6.08)
MgO	30.10	(33.60)	3.84	(4.00)	3.17	(3.39)	39.20	(44.00)	35.00	(40.00)	2.48	(2.52)
CaO	2.89	(3.23)	4.26	(4.43)	7.94	(8.49)	1.15	(1.29)	0.74	(0.85)	4.21	(4.29)
Na_2O	0.05	(0.06)	4.58	(4.77)	4.86	(5.19)	0.03	(0.03)	0.03	(0.03)	5.50	(5.60)
K_2O	—	—	0.90	(0.94)	0.94	—	—	—	0.00	—	0.92	(0.93)
TiO_2	0.26	(0.29)	0.60	(0.62)	0.79	(0.84)	0.13	(0.15)	0.13	(0.15)	0.61	(0.62)
P_2O_5	0.06	(0.07)	0.12	(0.12)	0.17	(0.18)	0.01	(0.01)	0.01	(0.01)	0.15	(0.15)
S	0.10	(0.10)	0.01	(0.01)	0.03	(0.03)	0.11	(0.11)	2.66	—	0.54	(0.54)
MnO	0.17	(0.19)	0.15	(0.16)	0.47	(0.50)	0.13	(0.15)	0.09	(0.10)	0.18	(0.18)
CO_2	4.85		2.56		3.74		1.48		1.92		0.19	
H_2O^+	5.28		2.84		2.21		10.25		8.79		0.45	
H_2O^-	1.85		0.02		0.95		0.37		0.48		0.47	
Ni	0.230		0.008		0.005		0.340		2.64		0.003	
Cu	0.009		0.004		0.005		0.002		0.01		0.002	
Total	102.23		101.51		100.41		101.84		102.05		99.20	

	J75-36		C76-36		C76-37		C76-38		C76-41		C76-54	
SiO_2	30.90	(33.70)	38.00	(43.32)	37.00	(41.23)	39.50	(43.48)	39.20	(43.26)	37.70	(42.57)
Al_2O_3	3.00	(3.28)	3.00	(3.42)	2.93	(3.26)	3.48	(3.83)	4.48	(4.94)	5.63	(6.35)
FeO*	22.60	(12.00)	7.62	(8.68)	11.48	(12.79)	7.32	(8.07)	8.95	(9.87)	6.71	(7.57)
MgO	25.20	(27.50)	37.30	(42.53)	36.90	(41.12)	37.70	(41.59)	32.10	(35.43)	33.40	(37.71)
CaO	2.59	(2.83)	1.41	(1.60)	1.02	(1.13)	2.16	(2.38)	5.35	(5.90)	4.25	(4.79)
Na_2O	0.05	(0.05)	—	—	0.01	(0.01)	0.10	(0.10)	0.00	(0.00)	0.00	(0.00)
K_2O	0.07	(0.08)	—	—	0.01	(0.01)	0.02	(0.02)	0.00	(0.00)	0.00	(0.00)
TiO_2	0.23	(0.25)	0.19	(0.21)	0.17	(0.18)	0.18	(0.19)	0.24	(0.26)	0.66	(0.74)
P_2O_5	0.02	(0.02)	0.01	(0.01)	—	—	0.00	(0.00)	0.01	(0.01)	0.00	(0.00)
S	7.69	—	0.03	(0.03)	0.08	(0.08)	0.04	(0.04)	0.04	(0.04)	0.02	(0.02)
MnO	0.16	(0.17)	0.18	(0.15)	0.14	(0.15)	0.15	(0.16)	0.18	(0.19)	0.23	(0.25)
CO_2	2.88		0.14		0.12		0.13		0.15		0.14	
H_2O^+	8.06		10.10		9.86		9.45		8.18		9.07	
H_2O^-	0.36		0.76		0.70		0.79		0.77		0.73	
Ni	1.64		0.188		0.234		0.124		0.110		0.132	
Cu	0.20		0.003		0.013		0.015		0.001		0.0005	
Total	105.64		98.89		100.64		101.13		99.81		98.63	

Table 2 - continued

	C76-61		C75-34		C76-150		C76-58		C76-17		J75-313		J75-314	
SiO_2	36.10	(41.10)	47.30	(48.70)	56.70	(58.46)	46.40	(47.23)	53.20	(54.67)	38.90	(42.00)	60.20	(61.10)
Al_2O_3	3.23	(3.67)	14.50	(14.90)	16.50	(17.01)	9.28	(9.44)	15.10	(15.51)	4.64	(5.01)	16.50	(16.80)
FeO*	11.88	(13.52)	13.80	(14.26)	4.47	(4.60)	13.19	(13.41)	7.99	(8.21)	12.13	(0.00)	5.79	(5.89)
MgO	34.00	(38.75)	8.12	(8.36)	2.89	(2.97)	12.10	(12.31)	5.84	(6.00)	30.30	(32.70)	4.73	(4.80)
CaO	2.24	(2.55)	8.08	(8.32)	9.35	(9.64)	13.20	(13.43)	7.84	(8.05)	4.29	(4.63)	3.44	(3.49)
Na_2O	0.00	(0.00)	2.80	(2.88)	4.98	(5.13)	0.75	(0.76)	4.58	(4.70)	0.11	(0.12)	4.31	(4.38)
K_2O	0.00	(0.00)	0.86	(0.89)	0.07	(0.07)	0.13	(0.13)	0.65	(0.66)	0.06	(0.06)	2.58	(2.62)
TiO_2	0.19	(0.21)	1.33	(1.37)	1.44	(1.48)	0.94	(0.95)	1.16	(1.19)	0.24	(0.26)	0.51	(0.52)
P_2O_5	0.02	(0.02)	0.15	(0.15)	0.15	(0.15)	0.06	(0.06)	0.10	(0.10)	0.02	(0.02)	0.10	(0.10)
S	0.01	(0.01)	0.01	(0.01)	0.26	(0.26)	0.02	(0.02)	0.56	(0.57)	2.13	(0.00)	0.21	(0.21)
MnO	0.15	(0.17)	0.13	(0.13)	0.08	(0.08)	0.26	(0.28)	0.24	(0.24)	0.14	(0.15)	0.08	(0.08)
CO_2	0.16		0.20		0.17		0.20		0.24		0.26		0.30	
H_2O^+	9.42		3.95		1.88		2.08		1.87		7.94		2.55	
H_2O^-	0.79		0.33		0.57		0.59		0.59		0.61		0.30	
Ni	0.184		0.023		0.006		0.004		0.032		0.92		0.024	
Cu	0.0005		0.010		0.004		0.002		0.014		0.07		0.003	
Total	98.38		101.63		99.60		101.14		100.04		102.79		101.63	

*iron is calculated as total iron and expressed as FeO. Where applicable iron values are corrected for high sulphur content in rocks.
**Numbers in parentheses represent anhydrous values.

LIST OF SPECIMEN LOCATIONS AND DESCRIPTIONS:

J75-15 - Cumulate peridotite (No.2 zone), level 622, sub south
J75-18 - Fine-grained bleached volcanic - Langmuir (No.2 zone), 6th Level, at footwall
C76-241 - Banded tuff, Langmuir (No.1 zone), DDH 76-7, 185 m, near footwall
J75-107 - Cumulate peridotite, Texmont deposit, 104 m above footwall contact
J75-108 - Cumulate peridotite with disseminated sulphides, Texmont, underground
J75-96 - Fine-grained tuff, Texmont, footwall area near line 50 + 00N, mine grid
J75-36 - Cumulate peridotite and net-textured sulphides, Alexo deposit, surface specimen near west waterhole at footwall
C76-36 - Cumulate peridotite, Alexo deposit, DDH 1957-10, 41.4 m
C76-37 - Partly carbonated cumulate peridotite, Alexo deposit, DDH 1957-10, 45.1 m
C76-38 - Cumulate peridotite, Alexo deposit, DDH 1957-51, 46 m
C76-54 - Cumulate peridotite, Alexo deposit, DDH 1957-11, 67 m
C76-61 - Cumulate peridotite, Alexo deposit, DDH 1957-12, 46 m
J75-34 - Fine-grained volcanic, Alexo deposit, surface near footwall
C76-150 - Bleached volcanic, Alexo deposit, DDH 27, 76.5 m (footwall)
C76-58 - Fine-grained pyroxenite, Alexo deposit, DDH 957-11, 112.1 m (margin of body)
C76-17 - Fine-grained bleached volcanic, Alexo deposit, DDH 1957-Z, 56.7m.

Abbreviations:
DDH - Diamond-drill hole

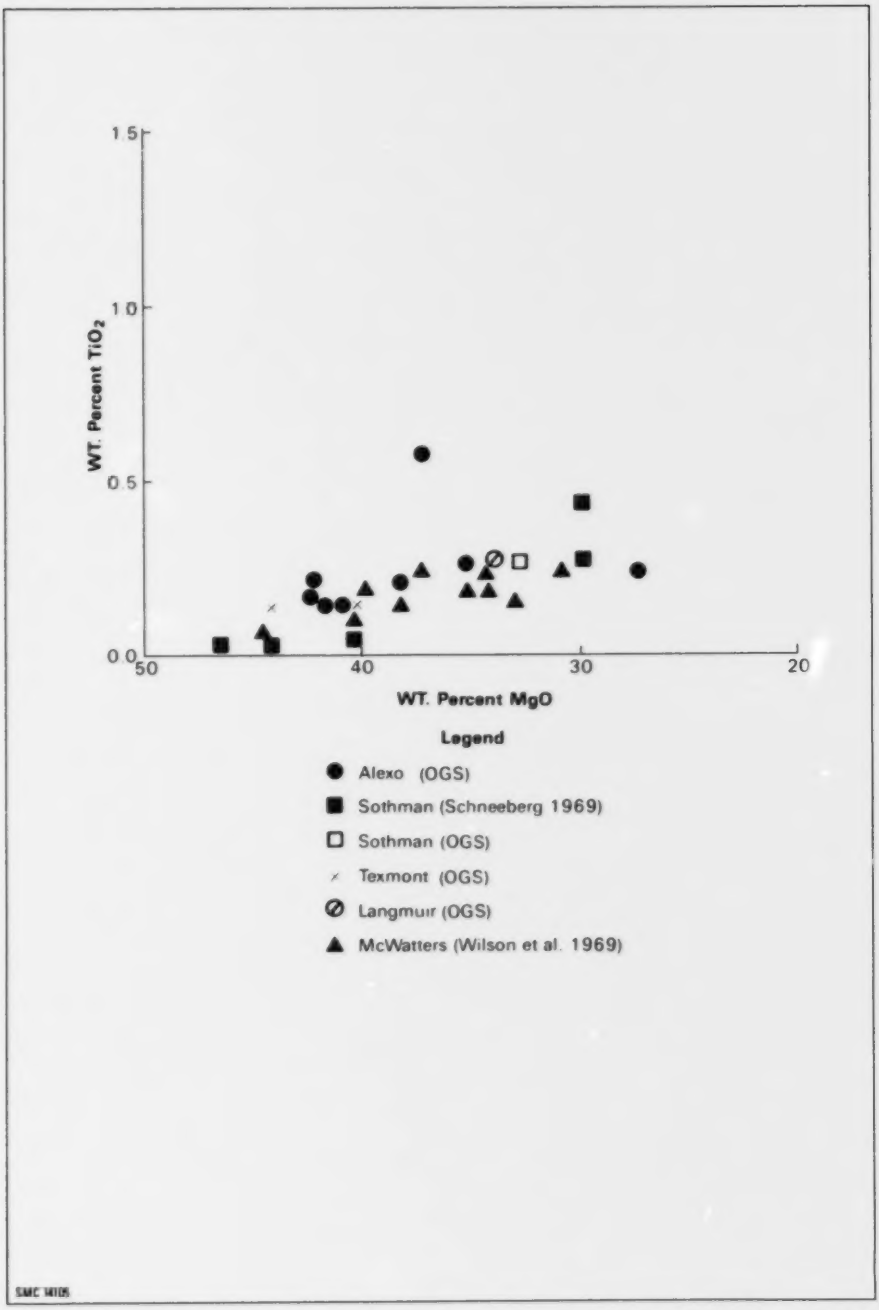
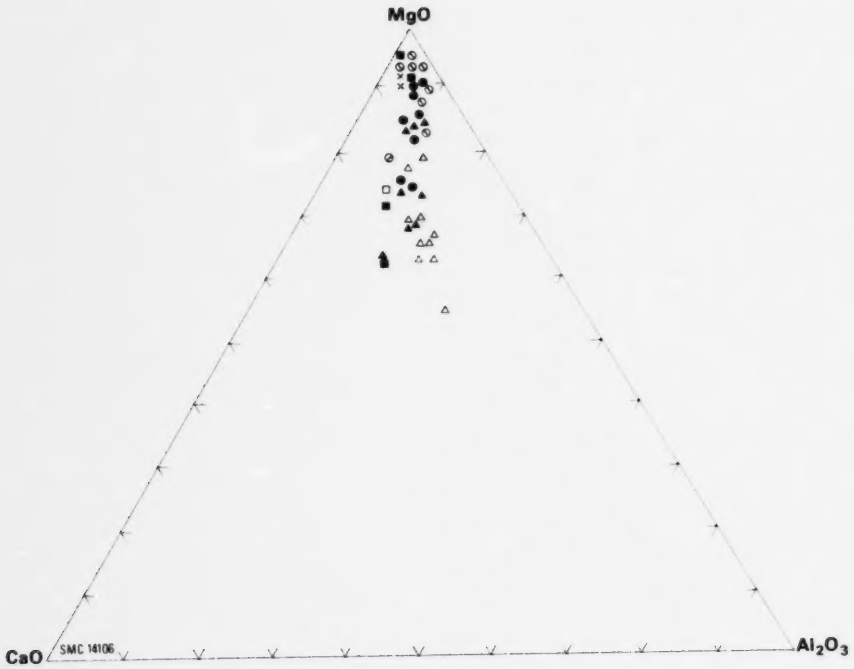


Figure 18–Weight percent TiO_2 versus MgO diagram for selected nickel deposits in the Abitibi Belt.



Legend

- ⊘ Langmuir (OGS)
- ⊘ Langmuir (Muir 1975)
- × Texmont
- ■ Sothman (OGS)
- □ Sothman (Schneeberg 1969)
- ● Alexo
- ▲ McWatters (Muir 1975)
- △ Hart (Muir 1975)

Figure 19–MgO-CaO-Al_2O_3 triangular diagram for selected nickel deposits in the Abitibi Belt.

A.J. Naldrett and N.T. Arndt (1976) have demonstrated that in komatiitic-type nickel deposits, host rocks generally plot close to the MgO apex in a plot of MgO-CaO-Al_2O_3 reflecting their magnesian-rich nature. It is worthwhile to note that the most magnesian-rich rocks host the most significant nickel sulphide mineralization (Figure 19).

Footwall Rocks

A total of six volcanic rocks and two tuffs from the footwall of the Langmuir, Texmont, Alexo, and Sothman Deposits were analysed by the Geoscience Laboratories, Ontario Geological Survey (Table 2). These analyses indicate that footwall rocks from the Langmuir, Texmont, and Sothman Deposits have an intermediate to felsic composition representing rocks of the Deloro Group (Pyke 1975c). Footwall volcanic rocks from the McWatters and Hart deposits also have an intermediate to felsic composition (Muir 1975; Pyke 1970; 1975a) and occur at the same stratigraphic horizon.

Footwall volcanic rocks from the Alexo, Langmuir, and Sothman Deposits are locally altered and appear bleached near their contact. This is reflected chemically by significant increases in SiO_2, Al_2O_3 and Na_2O and relative depletions in FeO (total iron) and K_2O (see Table 2, analyses for specimens J75-18, J75-314, J76-150, C76-17). Variations in the relative amounts of MgO and FeO (total iron) in the footwall rocks is reflected in the difference between specimens J75-34, C76-150, and C76-17, all from the footwall of the Alexo Deposit.

Specimen C76-58 from the footwall of the Alexo Deposit, would appear to have a komatiitic affinity being relatively enriched in MgO and containing small amounts of Na_2O, K_2O, and TiO_2 (Table 2). The rock does not ideally characterize the komatiitic suite, as it contains high total iron (13.41 percent FeO anhydrous) and relatively high sodium (0.76 percent Na_2O anhydrous) reflecting some type of alteration.

GENETIC MODELS, A REVIEW

It is now recognized that nickel deposits associated with Archean ultramafic rocks generally occur in a host rock consisting of peridotite or dunite, which is a lava flow or hypabyssal sill forming an intricate part of early eugeosynclinal volcanism. These ultramafic rocks generally belong to the komatiitic magma suite as described by Arndt *et al.* (1976). The nickel deposits are generally confined to the basal parts of Archean stratigraphic successions, such as the lower ultramafic groups in the Abitibi Belt, or in the Eastern Goldfields area of Western Australia (Gemuts and Theron 1975).

Four genetic models to explain volcanogenic nickel sulphide have been proposed by: 1) A.J. Naldrett (1966); 2) A.J. Naldrett (1973); 3) J.R. Ross and G.M.F. Hopkins (1975); and 4) J. Lusk (1976). A sulphurization model was originally envisaged by Naldrett (1966) to explain nickel sulphide mineralization at the Alexo Deposit whereby a reaction occurred between introduced sulphur and

nickel-bearing silicates. The model was subsequently discounted by Naldrett (1973), but it is used to explain local occurrences of nickel mineralization at contacts of certain intrusive bodies. Nickel mineralization along the margins of a peridotite body which intrudes felsic volcanic rocks in the Mattagami Lake Deposit, Quebec, is considered to have formed by sulphurization processes (Labine, R., mine geologist, personal communication, 1976). R.L. Oliver and M. Ward (1971) suggest that sulphurization is impossible due to the great stability of nickel silicates. However, it is considered to be locally significant for secondary enrichment and modification during serpentinization and related alteration processes (Hudson 1973). Regardless of its local significance, sulphurization is not considered to be the origin for volcanogenic nickel sulphide deposits.

In the second model, Naldrett (1973) suggests that magmatic nickel sulphides have been transported by the host lava or magma as droplets of immiscible liquid, and that these deposits have settled out of an ultramafic flow consisting of olivine crystals suspended in an ultramafic liquid. Naldrett (1973) uses a "billiard-ball" model to explain the separation of immiscible sulphide from the host magma, whereby mercury (immiscible sulphide) is poured into a beaker of billiard balls (olivine phenocrysts) filled with water (ultramafic liquid). During horizontal movement and/or gravity segregation, dense mercury or immiscible sulphide will settle to the base of the beaker or flow to accumulate as massive sulphides. Sulphides which do not reach the base of the beaker or flow will be suspended about olivine phenocrysts forming disseminated or net-textured sulphides (Naldrett 1973).

In this model, depressions in the basal contacts of the peridotite bodies and/or the relief of the surface onto which the lavas were erupted may control sulphide accumulation because dense sulphide droplets tend to settle out more rapidly than silicate phenocrysts. It is thought that because of the high density of the droplets, they are not likely to be transported any great distance by their host magmas during horizontal movement following eruption or high-level emplacement (Kilburn *et al.* 1969; Naldrett 1973). Similar constraints act upon the olivine crystals that are suspended within the dunitic magma; they are also likely to settle during horizontal movement. Nickel sulphides and olivine-rich magma will occur close to a source of eruption or magmatic conduit in this model due to density and gravity considerations (Naldrett 1973). In a more recent paper, Naldrett and Cabri (1976) support this model and the idea of a mantle-derived immiscible sulphide, and emphasize the importance of the synvolcanic ultramafic environment.

Ross and Hopkins (1975) introduced a different model, as they consider that Naldrett's 1973 model does not explain certain features of the Kambalda deposits in Western Australia. Ross and Hopkins (1975) found four anomalous features as follows:

1) The sharp contact between the massive sulphide layer and underlying meta-basalt, and the absence of a selvage of chilled ultramafic rock at this interface;

2) The concentration of chromite at the base of both the massive sulphide zone and the disseminated sulphide zone;

3) The different spatial distribution of contact sulphides and overlying disseminated zones;

4) The anomalous concentrations of zinc at the interface of the massive and disseminated sulphide layers.

Ross and Hopkins (1975) suggest that the presence of chromite grains at the base of the disseminated zone (feature 2 above) could not be due to magmatic concentration in the billiard ball model (Naldrett 1973) as the top of the massive sulphide layer would be molten and chromite being more dense should then occur at the base of the massive sulphide zone.

Ross and Hopkins (1975) also suggest that the emplacement of the massive and disseminated sulphide layers as separate flow units into a zinc-rich aqueous environment would account for the four anomalous features listed above. This would also account for the sharp contact between the massive and disseminated sulphide zones.

Ross and Hopkins (1975) consider that viscosity differences, between the components of a mixture of molten sulphide, olivine crystals, and an ultramafic liquid, would result in segregation during vertical flow to yield a frontal section of sulphide melt and an olivine-rich distal section. This is further enhanced by unconstrained horizontal flow. They suggest that the separate components of the Kambalda-type mineralization could have been emplaced at slightly different times as a consequence of this viscosity difference, and as a result, explain the anomalies mentioned above. The idea, of early separation of a sulphide melt prior to emplacement of the host ultramafic has also been suggested by G.J.H. McCall and J. Leishman (1971) and Nesbitt (1971).

Recently, Lusk (1976) has suggested that a magmatic volcanic-extrusive origin does not explain features of massive nickel sulphide deposits as well as by an alternative volcanic-exhalative origin. Such an origin would account for mineralogical layering, local-stringer-ore, a relative enrichment in pyrite, zones of footwall bleaching, local abundance of millerite, and associated exhalative sedimentary rocks. In this volcanic exhalative model, Lusk (1976) suggests that the outpouring of hot ultramafic lava across top surfaces of deposits would partly melt the nickel copper sulphides, thereby generating the igneous textures observed.

The abundance of pyrite in some of the deposits is explained in the first two models (Naldrett 1973; Ross and Hopkins 1975) by the subsequent deformation and alteration of the original orebody. An abundance of primary pyrite is not considered possible in nickel sulphide ore derived from a magmatic sulphide melt (Naldrett 1973). Lusk (1976) accounts for the local abundance of pyrite in the ore by proposing a volcanic-exhalative origin for the entire ore zone.

GENETIC MODELS, A DISCUSSION

Certain characteristics of volcanogenic nickel sulphide deposits can be explained by all four genetic models. It is difficult to accept each model in its entirety. However, selected parts from each model provide for a better understanding of this type of nickel deposit.

Many of the features observed at the Langmuir Deposit, such as the irregular distribution of chromite, irregular distribution of massive and net-textured or disseminated sulphide zones, and the presence of massive zones or pods in the

underlying tuffs, can be explained by the model proposed by Ross and Hopkins (1975). This model might also explain the presence of sulphide-bearing spinifex textures at the Langmuir Deposit and also the Texmont and Alexo Deposits. Ross and Hopkins (1975) suggest that separate components of Kambalda-type mineralization, molten sulphide, olivine crystals, and ultramafic liquid, could have been emplaced at slightly different times as a consequence of viscosity differences. It is possible that sulphides located in the interblade areas of the spinifex were trapped during crystallization of the olivine blades, in a manner analogous to sulphides which occur about olivine crystals in net-textured mineralization. A replacement type of mineralization is not invoked to explain net-textured sulphides in a magmatic-volcanic origin (Naldrett 1973; Ross and Hopkins 1975) and does not appear to have caused mineralization in most spinifex-textured rock.

The distribution of net-textured and massive sulphides at the Alexo Deposit can be explained by Naldrett's "billiard-ball" model. However, it does not account for the distribution of chromite in the deposit where chromite is concentrated toward the centre of the Alexo body away from the base. The different distribution of sulphides and chromite at the Alexo Deposit would support Ross and Hopkins' suggestion of separate flow units involved in mineralization whereby the massive sulphide zone may have been emplaced as a separate unit. It is difficult to imagine why immiscible sulphides would settle out under the influence of gravity, as in Naldrett's model, and chromite would concentrate along with olivine crystals near the centre of the body. In this regard it is interesting to note that chromite grains in the Shangani Nickel Deposit, Rhodesia, occur throughout the disseminated zone and not at the base or top of the basal massive sulphide zone (Viljoen *et al.* 1976).

The likelihood of significant exhalative activity in the environment of nickel sulphide deposits as suggested by Lusk (1976) is indicated by the presence of anomalously high zinc and copper values in sedimentary units which occur throughout the Kambalda ultramafic pile (Ross and Hopkins 1975) and by the presence of iron sulphides and minor base metals in volcanic rocks and tuffs underlying this type of deposit in both Western Australia and the Abitibi Greenstone Belt of Canada (see "Langmuir, Texmont, Hart, and McWatters Deposits"). Pyrite-rich graphitic horizons occur throughout the ultramafic pile at Kambalda and occur locally at the Texmont Deposit. Exhalative activity could explain the abundance of pyrite in the nickel sulphide ores as occurs at the Langmuir Deposit. The distribution of sulphides in volcanic rocks and tuffs underlying the deposits may be due to the stratigraphic position of these deposits, that is near the top of an intermediate to felsic volcanic pile and base of an overlying cycle marked by ultramafic volcanic rocks. Exhalative activity should be expected to occur at this particular interval. Significant amounts of pyrite are reported to occur in pillow interstices underlying the Miriam Nickel Deposit, Western Australia (Hallberg *et al.* 1973).

Although the volcanic exhalative model (Lusk 1976) is not considered to be the origin for volcanogenic nickel sulphide deposits, the model cannot be completely discounted because nickel mineralization occurs in a lenticular lens along a rhyolite-andesite contact in the Sherlock Bay Nickel-Copper Deposit, Western Australia (Miller and Smith 1975). This mineralization is a long distance from a

barren ultramafic body. L.J. Miller and M.J. Smith (1975) suggest that stratigraphic, structural, and petrographic studies support the concept that the mineralization has been intruded into a fracture.

An exhalative-type of origin might be suggested by the occurrence of nickel mineralization in schists, far removed from peridotite in the Thompson Mine, Manitoba (Zurbrigg 1963), although this particular area has been subjected to considerable structural deformation. Similarly, it is difficult to explain the Jussi Deposit in the Kotalahti District of Finland, where nickel mineralization is located in quartzite schists, and has no apparent connection to mafic or ultramafic rocks (Haapala 1969).

Nickel mineralization is also reported to occur in: metasediments underlying the Scotia Deposit (Christie 1972); in iron formation underlying the Windarra Deposit (Robinson *et al.* 1973); in "sediment-relics" in the ultramafic rocks at the Redross Deposit (Dalgarno 1975); and in pyrrhotite-rich sedimentary rocks near the footwall of the Wannaway Nickel Deposit (Dalgarno 1975). All these deposits are located in Western Australia. A similar stratigraphic positioning of minor nickel mineralization is reported to occur in volcanic breccia and tuff at the Langmuir and Hart Deposits (see sections on "Langmuir Deposit" and "Hart Deposit"). In this regard, the aspect of exhalative nickel or the association of nickel mineralization and exhalative activity is also suggested by the presence of minor sphalerite in the nickel ore at the Windarra Deposit, Western Australia (Watmuff 1974), and the presence of minor pentlandite, chalcopyrite, and sphalerite in tuffaceous rocks near ultrabasic rocks located in Dubisson Township, Quebec, (Grenier 1967). This type of nickel mineralization, which is generally volumetrically insignificant may be due to subsequent remobilization of nickel from the main mineralized zone. However, magnesium, copper, chromium, nickel, and lead with iron oxide account for up to 60 weight percent of the exhalative sedimentary rocks presently forming on the crest of the East Pacific rise (Bostrom and Peterson 1966).

The presence of disseminated millerite and pyrite mineralization at the Langmuir Deposit, McWatters Deposit, and locally at the Texmont Deposit may possibly be due to exhalative activity as nickel can precipitate from low temperature aqueous solutions as the monosulphide (Zaritskiy 1972) and exist as millerite in nickel-rich assemblages below 300°C (Kullerud *et al.* 1969). The presence of pyrite and millerite in the ultramafic rock away from the mineralized zone at the Miriam Deposit, Western Australia (Hallberg *et al.* 1973) would support this view.

LOCATION OF NICKEL SULPHIDES IN HOST ROCKS, A REVIEW

In most volcanogenic nickel sulphide deposits and some intrusive ultramafic rocks, nickel sulphides are generally concentrated toward the stratigraphic base of the bodies in pockets or flexures along the lower contact. This basal positioning of sulphides has always suggested a magmatic segregation of liquid sulphides. In some deposits, however, sulphides do not occur along the basal contact. The irregular distribution of massive and disseminated nickel sulphide

TABLE 3 DISTRIBUTION OF MINERALIZATION IN VARIOUS VOLCANOGENIC AND INTRUSIVE ULTRAMAFIC NICKEL SULPHIDE DEPOSITS.

Deposit and Location	Type of Ultramafic	Location of Sulphides	Reference
Alexo, Ontario	Extrusive (?)	m.s. to d.s. along base of u.m. adjacent to f.w. volcanics or above pyroxene-rich margin	See this report
Texmont, Ontario	Extrusive	d.s. throughout u.m. pile also in thin zones 100 m above base of u.m. pile	See this report
Langmuir, Ontario	Extrusive	m.s. to d.s. along base of lower flow adjacent to flow contact. Local m.s. to d.s. 9 m above f.w. m.s. in f.w. volcanics d.s. in intrusive u.m.	See this report
McWatters, Ontario	Extrusive (?)	m.s. to d.s. located in centre of u.m. above volcanic f.w.	See this report
Sothman, Ontario	Extrusive (?)	d.s. along base of body d.s. 4 m above base	See this report
Hart, Ontario	Extrusive (?)	m.s. to d.s. along basal contact of u.m. d.s. in f.w. volcanic breccia	See this report
Katinig Sill, Ungava	Extrusive (?)	m.s. to d.s. at base of u.m.	Wilson *et al.* 1969
Dumont, Quebec	Intrusive	d.s. in zones in u.m. locally m.s. at base	Eckstrand 1975. Company reports
Marbridge, Quebec	Extrusive (?)	d.s. to m.s. in u.m. near upper contact	Naldrett and Gasparrini 1971
Manibridge, Manitoba	Extrusive (?)	m.s. to d.s. near h.w. of u.m.	Coats and Brummer 1971
Bucko Lake and Bowden Lake	Intrusive	d.s. throughout u.m. locally at base	Kilburn *et al.* 1969
Dumbarton, Manitoba	Intrusive	d.s. to m.s. in zones 100 m below base of u.m.	Kilburn *et al.* 1969
Thompson, Manitoba	Intrusive	m.s. - d.s. in schists far from u.m. d.s. in u.m.	Zurbrigg 1963
Renzy Lake, Quebec	Intrusive	d.s. - m.s. along base of u.m. d.s. above base in zones where olivine is coarse	Forrester 1957
Rankin Inlet, NWT	Extrusive	m.s. - d.s. along base of u.m. d.s. in shear above base	Naldrett and Garparrini 1971

Table 3 - Continued on next page

Table 3 - Continued

Deposit and Location	Type of Ultramafic	Location of Sulphides	Reference
Cardiff Hill, S. Rhodesia	Intrusive (?)	d.s. in centre of u.m.	Le Roex 1964
Kambalda, W. Australia	Extrusive	m.s. to d.s. at basal contact plus mineralized zones locally above basal contact	Ross and Hopkins 1975
Scotia, W. Australia	Extrusive	m.s. to d.s. at basal contact plus d.s. in f.w. metasediments	Christie 1975
Windarra, W. Australia	Intrusive-Extrusive	m.s. to d.s. near basal contact d.s. in f.w. iron formation m.s. to d.s. above basal contact	Roberts 1975
MT Clifford, W. Australia	Extrusive (?)	d.s. near base of u.m. d.s. in zones throughout u.m.	Travis 1975
St. Ives, W. Australia	Extrusive	mineralization in flow 300 m above f.w. basalt	Fisher 1974
Miriam, W. Australia	Extrusive	d.s. to m.s. in bands 3 to 12 m above basal contact	Gemuts 1975
Pioneer, W. Australia	Extrusive (?)	m.s. to d.s. at basal contact mineralization also 15 m above basal contact	Cox and Tyrwhitt 1975
Wannaway, W. Australia	Extrusive (?)	m.s. to d.s. at basal contact at depth; at surface is 12 m above base	Dalgarno 1975
Widgiemooltha, W. Australia	Extrusive	m.s. to d.s. in patches along basal contact	Dalgarno 1975
MT Edwards, W. Australia	Extrusive	mineralization in two separated basal flows	INAL Staff 1975
Spargoville, W. Australia	Extrusive		Andrews 1975
Location 1		m.s. to d.s. at upper contact of u.m.	
Location 2		m.s. to d.s. at base	
Location 3		m.s. to d.s. at base	
Black Swan, W. Australia	Intrusive (?)	d.s. 50 m above base of u.m.	Groves *et al.* 1974
Sherlock Bay, W. Australia	Intrusive	d.s. to m.s. along rhyolite-andesite contact u.m. near by	Miller and Smith 1975
Redross, W. Australia	Intrusive	m.s. to d.s. at f.w. and h.w. contacts	Dalgarno 1975
Nepean, W. Australia	Intrusive	m.s. to d.s. at base of u.m. also sulphides in zones above base	Sheppy and Rowe 1975

Table 3 cont.

Deposit and Location	Type of Ultramafic	Location of Sulphides	Reference
M.T. Heath, W. Australia	Intrusive	d.s. in centre of u.m.	Burt and Sheppy 1975
Perseverance, W. Australia	Intrusive	m.s. to d.s. at base	Martin and Allchurch 1975
Six-Mile, W. Australia	Intrusive	d.s. near base of u.m. d.s. near centre of u.m. d.s. in 2 zones 100 m above base	Turner and Ranford 1975
Weebo Bore, W. Australia	Intrusive	d.s. co-extensive with serpentinization Strongest near margins of body	Legge 1975

Abbreviations:
d.s. - disseminated sulphides
m.s. - massive sulphides
h.w. - hanging wall
f.w. - foot wall
u.m. - ultramafic

mineralization has already been described at the Alexo and Langmuir Deposits (see Sections on 'Alexo Deposit" and 'Langmuir Deposit"). In Table 3, the location of massive and disseminated sulphides in a number of volcanogenic and intrusive deposits is listed to illustrate their complex and irregular distribution.

Naldrett and Cabri (1976) suggest that the main criterion for the formation of a rich basal concentration of magmatic sulphides is that the host magma should be saturated in sulphur and in addition contain a reasonably high proportion of immiscible sulphide droplets which can then settle rapidly to form a continuous, thick sulphide blanket. It is thought that if this criterion is not met and sulphides segregate slowly as the crystallization of silicates proceeds, then the sulphides are likely to become mixed with the settling silicate crystals to form a disseminated zone of little economic significance.

MECHANISM OF ULTRAMAFIC EMPLACEMENT, A DISCUSSION

All the genetic models except the sulphurization model suggest that ultramafic rocks which host most Archean nickel deposits were emplaced as flows, with, or without spinifex. However, the emplacement nature of thin concordant bodies marked by a dunitic core with pyroxene-rich margins is not adequately explained.

Chemically, the latter type of body belongs to the komatiitic magma suite as

do most Archean rocks which host nickel deposits. However, field characteristics do not necessarily imply an extrusive or intrusive origin for this type of body.

The Alexo and Sothman Deposits occur in thin concordant bodies marked by a dunitic core with pyroxene-rich margins. Similar deposits include the following; Katinig Sill, Ungava (Wilson *et al.* 1969); the McWatters Deposit (Wilson *et al.* 1969); and the Miriam Deposit, Western Australia (Hallberg *et al.* 1973) which has a basal pyroxenitic margin measuring 2 m thick. It is thought that many of these bodies represent high-level sills which were intruded as a suspension of olivine crystals within an ultramafic liquid. The geometry of this type of body has been reproduced on a small scale in laboratory experiments. S. Bhattacharji (1967) has shown by using experiments that the separation of solids (phenocrysts) from the walls and their concentration at or near the centre of both vertical and horizontal conduits takes place. Flowage differentation of this type is confirmed by element profiles across the Katinig (Wilson *et al.* 1969) and the Alexo bodies (Naldrett 1964). Profiles of MgO show a marked increase of modal olivine toward the centres away from the margins of the bodies.

Bhattacharji (1967) has demonstrated that in simulated melts, containing more olivine crystals (50 percent by volume) in suspension, flowage differentiation of the above type is produced while in melts containing less olivine crystals (15 percent by volume) in suspension, gravity settling is more significant and element profiles which characterize the Alexo or Katinig bodies do not occur. In this latter type of melt where spinifex textures would best be developed, spinifex texture may result from the quenching of an ultramafic liquid from which olivine crystals have settled out (Pyke *et al.* 1973).

Basal margins of the Langmuir Deposit are characterized by pyroxene-rich rocks, especially in fragments in the breccia ore. Similarly the basal margin of the Shangani Deposit of Rhodesia is marked by pyroxenitic rocks (Viljoen *et al.* 1976). Obviously, some flow differentiation does take place towards the basal margins of spinifex-textured flows. Element profiles across basal parts of flows in Western Australia also reflect minor flow differentiation at the basal contact (Ross and Hopkins 1975).

At the Miriam Prospect, Western Australia, the peridotite body is overlain by chloritic-tremolitic rocks which contain spinifex textures (Hallberg *et al.* 1973). Presumably, these rocks resulted from an extruded liquid containing less olivine crystals in suspension and hence the development of spinifex.

It is possible that the Alexo, Sothman, McWatters, and Katinig Deposits represent extrusions of phenocryst-enriched ultramafic liquid. Under this physical constraint, flow dynamics will produce a body marked by an axial concentration of olivine crystals, and due to the small volume of ultramafic liquid and significant gravity setting, spinifex texture will be absent or not well developed.

An extrusive origin for the Alexo body is suggested by the intimate occurrence of hyaloclastite within the basal margin. Also spinifex-textures occur in pyroxene-rich lenses located to the west of the Alexo Deposit (Naldrett and Mason 1968) which appears to be stratigraphically equivalent and correlative with the Alexo Deposit. An extrusive origin for these lenses is also suggested by their fractionation trend in an MgO-CaO-Al_2O_3 diagram. This trend is very similar to that of ultramafic rocks in the Scotia area of Western Australia, now recognized to be flows (Nesbitt 1971). The pyroxene-rich lenses also resemble the peridotite which hosts the Mount Clifford Deposit, Western Australia (Travis 1975).

Skeletal crystals of olivine occur along the margins of peridotite. G.A. Travis (1975) suggests a volcanic or subvolcanic setting for the Mount Clifford Deposit. An extrusive origin for the Alexo Deposit is also suggested by the margins of the body, which in places compare in every respect to fragments in breccia-ore located at the Langmuir Deposit, a volcanogenic nickel deposit. The grain size of olivine crystals in the Alexo, Katiniq, Sothman, and McWatters Bodies compares with that in extrusive rocks hosting nickel deposits in Western Australia (Eckstrand 1974). The occurrence of coarse olivine crystals, those greater than 3.0 mm, should not necessarily be considered to represent an intrusive origin as coarse grain size may result from higher diffusion rates in these low viscosity melts.

The possibility of an extrusive origin for thin lenticular bodies with dunitic cores and pyroxene-rich margins should not necessarily be applied to large bodies which measure more than 100 m thick. These particular bodies probably do represent intrusive bodies.

ECONOMIC POTENTIAL OF MAFIC AND ULTRAMAFIC INTRUSIONS, A DISCUSSION

Intrusive mafic and ultramafic bodies are volumetrically insignificant as hosts for economic sulphide deposits, although they form an intricate part of all Archean greenstone belts. The intrusions are of variable size and occur as stratiform or discordant bodies which may or may not be layered and/or differentiated. Intrusions of gabbro or peridotite also occur simply as isolated bodies.

In Australia, mafic and ultramafic intrusions occur as layered, differentiated, stratiform, or non-stratiform sills. Concordant intrusions are considered to be penecontemporaneous with enclosing volcanic rocks representing eugeosynclinal volcanism (Williams and Hallberg 1973; McCall 1972). The Carr Boyd Deposit is the only significant nickel sulphide deposit in all the layered intrusive bodies of Australia (Purvis *et al.* 1972). In this deposit, nickel-copper mineralization occurs in pipe-like bodies of sulphide bronzite pegmatite which transgress a layered ultramafic complex. Similar deposits of this type include the Giant Nickel Deposit, British Columbia (Aho 1956) and pegmatite-type deposits in the Vlakfontein District of South Africa (Liebenberg 1970).

Generally disseminated sulphides occur in mafic rather than ultramafic rocks of layered intrusions as are seen in the Bushveld, Stillwater, Muskox, and the Duluth Complexes (Travis 1975). In each of these, the stratiform sulphides which occur in the basal or marginal zones are rarely of economic importance unless associated with significant platinum-group metals. The Lynn Lake Deposit, Manitoba, does represent an economic occurrence of nickel mineralization in a layered differentiated peridotite-gabbro sill (Emslie and Moore 1961). The orebodies occur in pyroxenite and norite close to the contact with the underlying peridotite. Grades of 0.84 percent nickel and 0.53 percent copper are reported to occur in ore reserves of 28 million tons (Naldrett and Gasparrini 1971). Orebodies of the Kotalahti District of Finland also represent an exception, where massive to disseminated nickel mineralization occurs throughout a large mafic-ultramafic intrusion (Haapala 1969). A layered stratiform ultramafic complex in the Limpopo Fold Belt, Rhodesia, does represent a typical mineralized complex where

disseminated sulphides occur in a transitional zone between bronzite and norite (Bouladon *et al.* 1972). It is interesting to note that minor massive nickel copper sulphides and associated disseminated sulphides occur locally, at the base of the Munni Munni Complex, a layered peridotite-gabbro body in Western Australia (Donaldson 1974; Miller 1975).

Discounting the Sudbury Deposits, the Noril'sk Deposit, U.S.S.R. (Godleveskii 1959) the Pechenga Deposit, Finland (Gorbunov 1959) and the Lynn Lake Deposit, Manitoba (Naldrett and Gasparrini 1971) appear to represent the only economic nickel sulphide deposits located in layered intrusions, other than the pipe-like deposits previously described. Layering is not reported in the complex mafic-ultramafic body which hosts nickel mineralization in the Kotalahti District of Finland (Haapala 1969). These deposits, particularly those at Sudbury, Pechenga, and Noril'sk indicate the importance of the tholeiitic magma suite in hosting economic nickel sulphide mineralization (Naldrett and Cabri 1976).

The Perseverance, Six-Mile, and Mount Keith Deposits, all located in Western Australia, represent unique types of intrusive nickel deposits. In the Perseverance Deposit, disseminated and massive mineralization occurs along the western margin of a lens shaped body of dunite serpentinite surrounding a core of dunite (Martin and Allchurch 1975). Locally, the body appears to be transgressive and intrusive into metasediments and metavolcanics. In the Six-Mile Deposit, sub-economic low grade disseminated mineralization occurs in a cumulate-textured serpentinite host which is interpreted as being a fault-controlled discordant intrusion transgressing part of a metasedimentary sequence (Turner and Ranford 1975). In the Mount Keith Deposit disseminated nickel mineralization is concentrated centrally in a serpentinized dunite which appears to have been emplaced as a dike-like body within a belt of metavolcanics and metasediments (Burt and Sheppy 1975). Ultramafic rocks in all three deposits belong to the komatiitic magma suite (Naldrett and Cabri 1976).

As indicated by Eckstrand (1974) these intrusive-type deposits resemble the Dumont Nickel Deposit in Quebec where disseminated nickel mineralization occurs in crude zones throughout a large lens-shaped serpentinite. Eckstrand (1975) suggests that the mineralization has been concentrated and modified by various alteration processes. Chemically, the Dumont serpentinite also appears to belong to the komatiitic suite (Duke, M.; Geological Survey of Canada 1976, personal communication).

Although most layered and/or differentiated intrusive rocks in Archean "greenstone" belts are generally barren of nickel deposits, they usually occupy a similar stratigraphic position with respect to extrusive ultramafic rocks. This stratigraphic positioning which is recognized in Australia, Canada, and South Africa may be significant in the exploration for volcanogenic nickel sulphide deposits.

In the Eastern Goldfields region of Western Australia, intrusive layered sills occur in close proximity to ultramafic flows and high magnesium-basalts (Williams and Hallberg 1973). The exact stratigraphic relationship between the sills and flows is not clear in many localities due to tight isoclinal folding and poor outcrop exposure. Generally, however, the sills underlie the ultramafic flows or lenses. A large ultramafic intrusion, up to 1000 m thick underlies the Mount Clifford Nickel Deposit (Travis 1975). The intrusive body consists of tightly packed olivine grains measuring 3 to 6 mm in diameter. Several sill-like gabbroic intru-

sive rocks occur throughout this large body and separate it from the overlying mineralized ultramafic flows. Similarly, a layered ultramafic body stratigraphically underlies the Sherlock Bay Nickel-Copper Deposit in Western Australia (Miller and Smith 1975).

In the Abitibi Belt, intrusions of dunite and peridotite occur throughout the upper parts of the Deloro Group and are considered to be reservoirs or feeders to overlying flows marking basal parts of the Tisdale Group (Pyke 1975a). Large layered complexes and layered-differentiated sills are well represented in the Abitibi Belt by the Dore Lake Complex, Chibougamau area (Allard 1970), the Bell River Complex of the Matagami area (Sharpe 1965), the Kamiskotia Complex west of Timmins (Wolfe 1970) and numerous peridotite-gabbro sills (MacRae 1969; Naldrett and Mason 1968). The Dore Lake and Bell River Complexes consist of alternating stratiform layers of anorthosite, pyroxenite, and gabbro. Anorthosite layers are particularly common toward the base of each complex. The Kamiskotia Complex consists essentially of gabbro and anorthosite with minor peridotite and appears to occur near the top of the Deloro Group.

Nickel sulphide deposits are not associated with these large layered complexes, all of which belong to the tholeiitic-type of magma suite (Naldrett and Cabri 1976). The Alexo Deposit does, however, represent a nickel deposit located stratigraphically above the Dundonald Sill, a large differentiated tholeiitic peridotite-gabbro body (Naldrett and Mason 1968). The Dundonald Sill is separated from the Alexo Deposit by magnesium-rich basalts and local occurrences of intermediate to felsic volcanic rocks (Naldrett 1964).

In Rhodesia, the Shangani Nickel Deposit is underlain by a layered ultramafic body. M.J. Viljoen *et al.* (1976) suggest that the layered body is younger and has intruded the mineralized ultramafic flows of the Shangani Deposit. However, structurally the area is quite complex and age relationships are not clearly defined. The Epoch Nickel Deposit, also in Rhodesia, resembles the Shangani Deposit in that it too is underlain by a layered ultramafic body. In this deposit nickel mineralization occurs in an unusual ultramafic complex which apparently branches from a well-developed and more extensive layered ultramafic body (Viljoen *et al.* 1976).

The genetic relationship between the various layered intrusions and overlying ultramafic flows is not clear. However, it would appear that the stratiform intrusions are contemporaneous with eugeosynclinal volcanism. Viljoen and Viljoen (1970) suggest that layered ultramafic intrusions in the lower part of the Onverwacht Group are intrusive equivalents of extrusive komatiites located in the same group. In this regard the Dundonald Sill does not appear to be genetically related to the overlying Alexo Deposit because it plots as a tholeiite in a graph of Al_2O_3 versus $FeO/(FeO+MgO)$, reflecting its high FeO/MgO ratio and low Al_2O_3 content (Naldrett and Cabri 1976). The Alexo body itself belongs to the komatiitic suite (see "Alexo Deposit").

Although chemical continuity, with respect to type of magma suite, has not been documented between the various layered intrusive complexes and overlying extrusive ultramafic rocks, it would appear that a stratigraphic positioning of such bodies does exist. Thus layered intrusions which seldom host nickel sulphide deposits may aid in the exploration for volcanogenic-type nickel sulphide deposits as a type of stratigraphic marker. Perhaps this stratigraphic positioning reflects some type of paleo-crustal weakness or mantle crustal event which has

caused the localization of both intrusive and extrusive bodies to the same relative stratigraphic position.

The economic potential of the various types of mafic and ultramafic bodies is quite variable. However, it appears to depend more on the form of intrusion and not the particular type of magmatic suite, whether it is tholeiitic or komatiitic. It would appear that layered ultramafic bodies are not likely to host economic nickel sulphide deposits, though there are exceptions to this. Intrusive dunitic bodies of the komatiitic suite may make good exploration targets for the Perseverance-type of nickel sulphide deposit.

The economic potential of the simple mafic intrusion for hosting nickel sulphide deposits is provided by the recent Teck Discovery located north of Timmins, Ontario (Northern Miner, October 14th and 21st, November 4, 1976). In this deposit, disseminated nickel-copper mineralization in approximately a 1:1 ratio occurs in a gabbro to dioritic body. The Renner Deposit, a gabbro to dioritic body located in the Algoma district is similar to the Teck Discovery, but the nickel/copper ratio is slightly greater than unity. Ore tonnage in this deposit has been estimated to be 2,888,000 tons grading 0.29 percent nickel and 0.26 percent copper or 161,400 tons grading 1.08 percent nickel and 0.71 percent copper for higher grade material (Shklanka 1969). The Cat Lake Deposit in Manitoba is also located in a gabbroic intrusion. Grades of 0.33 percent nickel and 0.75 percent copper are reported to occur in an estimated 2.0 million tons of ore (Karup-Moller and Brummer 1971). Similarly, disseminated nickel-copper mineralization occurs in the Great Lakes Nickel Deposit, Ontario, a discordant gabbro-anorthosite body (Shklanka 1969).

All these deposits occur in rocks less magnesia rich than komatiitic-type peridotites, and therefore contain significant amounts of copper as well as nickel mineralizaion. In this regard, they resemble the tholeiitic-type of mafic or ultramafic intrusion having high copper/copper-nickel ratios (Naldrett and Cabri 1976). This type of deposit is generally characterized by large tonnage low grade mineralization, whereas the komatiitic type of deposit generally represents a small tonnage high grade deposit.

The Macassa Nickel Deposit in Limerick Township, Hastings County, Ontario also illustrates the economic potential of the mafic-type of intrusion. In this deposit, nickel mineralization occurs in a pyroxenitic body adjacent to gabbro (Shklanka 1969). Ore tonnage has been calculated to be 2,000,000 tons grading 1.0 percent nickel and 0.25 percent copper (Northern Miner 1962).

SUMMARY AND CONCLUSIONS

A compromise between a magmatic-volcanic-exhalative origin is warranted to explain the nature of Archean volcanogenic nickel sulphide deposits. The irregular distribution of massive and disseminated sulphide layers indicates that they are probably emplaced as separate flow units (Ross and Hopkins 1975). The concentration of sulphur and immiscible sulphides in a magma (Naldrett and Cabri 1976), the degree of sulphide segregation prior to emplacement, the proportion of olivine phenocrysts and ultramafic liquid relative to immiscible sulphides, the completeness of gravity segregation, the effects of mixing magmatic

and exhalative processes, and the conditions of pre- and post-ore environments would account for the various features observed at the different deposits.

The stratigraphic position and geological environment which hosts the nickel deposits in the Abitibi Greenstone Belt would suggest an environment favourable for exhalative activity as evidenced by the presence of mineralized metavolcanics, felsic breccia, tuff, and local iron formation underlying the Texmont, Langmuir, Hart, McWatters, Sothman, and Alexo Deposits. The presence of mineralized volcanic breccia and local faults in the stratigraphic footwall could indicate zones of structural weakness and areas of possible feeder-pipes for extrusive ultramafic volcanic rocks and associated nickel sulphide mineralization. At the Texmont Deposit, the location of a post-ore dike, and outcrop of peridotite in footwall breccia could indicate the presence of a feeder-pipe. Ultramafic rocks in the Shangani Nickel Deposit of Rhodesia, have been interpreted as being extruded through a felsic vent, now marked by felsic agglomerate (Viljoen *et al.* 1976).

The recognition of the various geochemical and field parameters (Naldrett and Cabri 1976) distinguishing komatiites from tholeiites is important as the former magmatic suite is a more favourable host for nickel sulphide deposits. Nickel deposits which occur in rocks belonging to the tholeiitic magma suite will invariably contain significant amounts of copper as well as nickel mineralization. The importance of the intrusive as well as the extrusive komatiite is provided by the various nickel deposits associated with intrusive komatiitic bodies in Western Australia.

The layered type of ultramafic body, although generally barren of economic nickel sulphide mineralization, may provide stratigraphic control during the exploration for volcanogenic nickel sulphide deposits.

Mafic intrusions, representative of the tholeiitic series, may host large tonnage, low grade types of deposits where both copper and nickel mineralization occur.

Massive nickel sulphide mineralization generally predominates in extrusive komatiitic flow environments. The recognition of komatiitic flow characteristics is important (Pyke *et al.* 1973) as well as the recognition of possible extrusive emplacement for lenticular dunitic lenses with pyroxene-rich margins. Massive to disseminated nickel sulphide mineralization occurs in this type of ultramafic body as evidenced by the Alexo, Katiniq, and McWatters Deposits, and disseminated mineralization alone occurs in the Sothman and Mount Clifford Deposits (see appropriate sections in this report).

Large intrusive bodies of komatiite are generally characterized by disseminated-type mineralization. However, massive nickel sulphides occur in the Perseverance and Nepean Deposits, both of which are intrusive.

The significance of bleached volcanic rocks at both the Langmuir and Alexo Deposits in the Abitibi Greenstone Belt, and at the Scotia and Nepean Deposits, Western Australia, is not clear. However, the bleaching may be attributed to volcanic exhalative activity about a volcanic centre or about the emplacement of the ultramafic volcanic rocks and their associated sulphides. Regardless of the genetic significance, bleached or altered volcanic rocks might possibly be useful in delineating nickel mineralization in favourable environments.

Nickel Sulphide Deposits

The following points might be useful in the practical exploration for nickel sulphide deposits associated with ultramafic volcanic rocks and intrusive ultramafic bodies:

1 - The significance of stratigraphic control, particularly in the Timmins camp. Efforts might best be directed toward ultramafic units located at the base of the Tisdale Group (Pyke 1975c). Similar stratigraphic settings in other belts should be regarded as favourable target areas such as those in Western Australia (Gemuts and Theron 1975);

2 - The presence of felsic volcanic breccia in the footwall of ultramafic sequences. These rocks may delineate centres through which ultramafic flows were extruded. Sulphide mineralization may be localized in the ultramafic pile above such centres;

3 - Significant crustal sutures, faults, or fissures might also serve as conduits for the volcanogenic-type of deposit;

4 - Volcanic rocks which underlie volcanogenic nickel sulphide deposits are invariably mineralized by disseminated iron sulphides and minor base metals;

5 - Volcanic rocks which underlie volcanogenic nickel sulphide deposits are locally bleached or altered;

6 - Komatiites appear to host more nickel sulphide deposits than ultramafic bodies belonging to the tholeiitic suite;

7 - Not all komatiites host nickel sulphide mineralization. Komatiites which host nickel sulphide deposits generally have high MgO contents ($>$ 35 percent), contain appreciable amounts of sulphur, and represent an integral part of early eugosynclinal volcanism;

8 - Nickel sulphide deposits in rocks of the tholeiitic suite generally have a higher copper/copper and nickel ratio than komatiitic-type deposits;

9 - The presence of well-developed spinifex-textured flows should indicate proximity to a volcanic conduit or centre. Komatiitic lavas may or may not exhibit spinifex texture; this is a function of the original phenocryst/liquid ratio in the melt.

10 - The coincidence of a relatively thick sequence of komatiitic lavas and/or concentration of intrusive ultramafic bodies might be interpreted as being at or proximal to a large volcanic centre and therefore, possible economic sulphide mineralization.

11 - Massive and disseminated nickel sulphides are irregularly distributed in many deposits and not necessarily concentrated towards the stratigraphic base of the host ultramafic rock;

12 - Extrusive komatiites may host massive and/or disseminated nickel sulphide mineralization. Intrusive komatiites generally host disseminated-type mineralization;

13 - Lenticular lenses of dunite with pyroxene-rich margins may host significant amounts of both massive and disseminated nickel sulphide mineralization;

14 - Disseminated-type nickel sulphide mineralization may be locally enriched or concentrated during serpentinization and/or talc carbonate alteration (Eckstrand 1975);

15 - Large layered ultramafic complexes may be used as a stratigraphic control when searching for extrusive ultramafic rocks. Extrusive ultramafic rocks generally overlie layered ultramafic complexes in a volcanic pile. In an environment where both layered intrusive and extrusive ultramafic rocks occur, the extrusive units will be more likely to host significant amounts of nickel sulphides;
16 - The recognition of penecontemporaneous faults and/or paleographic depressions in a favourable environment might indicate areas favourable for significant sulphide concentration; and
17 - In favourable ultramafic rock environments disseminated zones of pyrite and millerite mineralization could indicate rich concentrations of nickel sulphide further removed along strike or down dip.

APPENDIX

GLOSSARY OF TECHNICAL TERMS

Cruciform - a textural term used to describe an array of "stacked" chromite crystals.
Exhalative - hydrothermal processes accompanying volcanism.
Hyaloclastite - tuff formed by the flowing of basalt under water or ice and its consequent granulation or sheltering into small angular fragments - syn. "aquagene tuff".
Komatiitic - a magnesian-rich magma suite which is characterized by spinifex-textured ultramafic flows, a low $FeO/(FeO+MgO)$ ratio for a given Al_2O_3 content (where total iron is calculated as FeO), and relatively low TiO_2 contents (Naldrett and Cabri 1976).
"Net-Texture" - a descriptive term used to describe nickel sulphides forming a continuous net between equant grains of serpentinized olivine (Naldrett 1973).
Spinifex - a descriptive textural term used to describe random or parallel, generally elongate, blades of olivine.
Tholeiitic - a less magnesian rich magma suite, lacking spinifex texture and having a higher $FeO/(FeO+MgO)$ ratio and TiO_2 content than komatiites (Naldrett and Cabri 1976).
Volcanogenic - directly associated with and/or part of volcanism.

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